COE 180701 – REVIEW THE CURRENT SAMI NOISE EXPOSURE LIMIT AND CONDUCT A STUDY ON VIBRATION OEL IN RELATION TO THE SAMI

Final Report

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Elimination

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### 12.5.2 Engineering control

Engineering control

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Administrative control

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Mechanised drill and blast and non-explosive mining

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<th>Description</th>
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<tr>
<td># or No.</td>
<td>Number</td>
</tr>
<tr>
<td>%</td>
<td>Percentage</td>
</tr>
<tr>
<td>&lt;</td>
<td>Less than</td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than</td>
</tr>
<tr>
<td>≤</td>
<td>Equal to or less than</td>
</tr>
<tr>
<td>≥</td>
<td>Equal to or greater than</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees Celsius</td>
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<tr>
<td>2D</td>
<td>Two-dimensional</td>
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<tr>
<td>3D</td>
<td>Three-dimensional</td>
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<tr>
<td>ACGIH</td>
<td>American Conference of Government Industrial Hygienists</td>
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<tr>
<td>ADT</td>
<td>Articulated Dump Truck</td>
</tr>
<tr>
<td>ANC</td>
<td>Active Noise Control</td>
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<tr>
<td>AUG</td>
<td>Augmentation</td>
</tr>
<tr>
<td>aw</td>
<td>Weighted acceleration</td>
</tr>
<tr>
<td>BEI</td>
<td>Biological Exposure Indices</td>
</tr>
<tr>
<td>CAT</td>
<td>Caterpillar</td>
</tr>
<tr>
<td>CDC</td>
<td>Centre for Disease Control and Prevention</td>
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<tr>
<td>CF</td>
<td>Crest Factor</td>
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<tr>
<td>CloM</td>
<td>Chief Inspector of Mines</td>
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<tr>
<td>CM</td>
<td>Continuous Miner</td>
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<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>CoE</td>
<td>Centre of Excellence</td>
</tr>
<tr>
<td>COM</td>
<td>Chamber of Mines of South Africa</td>
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<tr>
<td>COMRO</td>
<td>Chamber of Mines Research Organization</td>
</tr>
<tr>
<td>COP</td>
<td>Code of Practice</td>
</tr>
<tr>
<td>CSIR</td>
<td>Council for Scientific and Industrial Research</td>
</tr>
<tr>
<td>CTD</td>
<td>Cumulative Trauma Disorder</td>
</tr>
<tr>
<td>CTS</td>
<td>Carpal Tunnel Syndrome</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
</tr>
<tr>
<td>dBA</td>
<td>Decibel (measured with A-filter)</td>
</tr>
<tr>
<td>dBC</td>
<td>Decibel (measured with C-filter)</td>
</tr>
<tr>
<td>dBL_{Aeq,8h}</td>
<td>A-weighted equivalent continuous sound level in decibels measured over an 8-hour time period</td>
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<tr>
<td>dBL_{A,8h}</td>
<td>Rating level over an 8-hour time period</td>
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<td>DMRE</td>
<td>Department of Mineral Resources and Energy</td>
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<tr>
<td>Dy</td>
<td>Vibration Dose</td>
</tr>
<tr>
<td>EAV</td>
<td>Exposure Action Value</td>
</tr>
<tr>
<td>EC</td>
<td>European Council</td>
</tr>
<tr>
<td>ELV</td>
<td>Exposure Limit Value</td>
</tr>
<tr>
<td>EMP</td>
<td>Electromagnetic Pulse</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FEL</td>
<td>Front End Loader</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>h</td>
<td>Hours</td>
</tr>
<tr>
<td>HA</td>
<td>Hand-arm</td>
</tr>
<tr>
<td>HAV</td>
<td>Hand-arm Vibration</td>
</tr>
<tr>
<td>HAVS</td>
<td>Hand-arm Vibration Syndrome</td>
</tr>
<tr>
<td>HCP</td>
<td>Hearing Conservation Programme</td>
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<tr>
<td>HCS</td>
<td>Hazardous Chemical Substances</td>
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<td>HEG</td>
<td>Homogeneous Exposure group</td>
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<td>HGCZ</td>
<td>Health Guidance Caution Zone</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<td>-------------</td>
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<tr>
<td>HIV</td>
<td>Human Immunodeficiency Virus</td>
</tr>
<tr>
<td>HL</td>
<td>Hearing Loss</td>
</tr>
<tr>
<td>HPD</td>
<td>Hearing Protection Devices</td>
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<tr>
<td>HR</td>
<td>Human Resources</td>
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<td>ILO</td>
<td>International Labour Organisation</td>
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<tr>
<td>IOSH</td>
<td>Institute of Occupational Health and Safety</td>
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<tr>
<td>ISO</td>
<td>International Organisation for Standards</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>kPa</td>
<td>Kilo-Pascal</td>
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<tr>
<td>kW</td>
<td>Kilowatt</td>
</tr>
<tr>
<td>LBP</td>
<td>Low Back Pain</td>
</tr>
<tr>
<td>LDV</td>
<td>Light Duty Vehicle</td>
</tr>
<tr>
<td>LHD</td>
<td>Load Haul Dumper</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
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<tr>
<td>m/s(^{1.75})</td>
<td>Meters per second to the power of 1.75</td>
</tr>
<tr>
<td>m/s(^{2})</td>
<td>Meter per second squared</td>
</tr>
<tr>
<td>max</td>
<td>Maximum</td>
</tr>
<tr>
<td>MCSA</td>
<td>Minerals Council South Africa</td>
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<tr>
<td>MDI</td>
<td>Methylene Diphenyl Diisocyanate</td>
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<tr>
<td>MHS</td>
<td>Mine Health and Safety</td>
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<td>MHSAct</td>
<td>Mine Health and Safety Act, Act 29 of 1996</td>
</tr>
<tr>
<td>MHSC</td>
<td>Mine Health and Safety Council</td>
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<td>min</td>
<td>Minimum</td>
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<td>mm</td>
<td>Millimeter</td>
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<tr>
<td>MOSH</td>
<td>Mine Occupational Health and Safety initiative</td>
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<tr>
<td>MPa</td>
<td>Megapascal</td>
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<tr>
<td>MTVVV</td>
<td>Maximum Transient Vibration Value</td>
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<td>n.d.</td>
<td>no date</td>
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<td>N/A</td>
<td>Not Applicable</td>
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<td>NIHL</td>
<td>Noise Induced Hearing Loss</td>
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<td>NIOSH</td>
<td>National Institute for Occupational Safety and Health</td>
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<td>NRR</td>
<td>Noise Reduction Rating</td>
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<tr>
<td>OEL</td>
<td>Occupational Exposure Limit</td>
</tr>
<tr>
<td>OSHA</td>
<td>Occupational Safety and Health Administration</td>
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<tr>
<td>Pa</td>
<td>Pascal</td>
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<tr>
<td>PEL</td>
<td>Permissible Exposure Limit</td>
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<tr>
<td>PPE</td>
<td>Personal Protective Equipment</td>
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<tr>
<td>ppm</td>
<td>Parts per million</td>
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<tr>
<td>PTS</td>
<td>Permanent Threshold Shift</td>
</tr>
<tr>
<td>R</td>
<td>South African Rand</td>
</tr>
<tr>
<td>rad/s(^{2})</td>
<td>Radians per second squared</td>
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<tr>
<td>RAS</td>
<td>Reticular Activating System</td>
</tr>
<tr>
<td>RMA</td>
<td>Rand Mutual Assurance Company Limited</td>
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<tr>
<td>RMS or r.m.s</td>
<td>Root mean square</td>
</tr>
<tr>
<td>SAMI</td>
<td>South African Mining Industry</td>
</tr>
<tr>
<td>SAMOHP</td>
<td>South African Mines Occupational Hygiene Programme</td>
</tr>
<tr>
<td>SANS</td>
<td>South Africa National Standard</td>
</tr>
<tr>
<td>SDMats</td>
<td>Sound Dampening Mats</td>
</tr>
<tr>
<td>Sed</td>
<td>Daily equivalent static compressive dose</td>
</tr>
<tr>
<td>SEG</td>
<td>Similar Exposure Group</td>
</tr>
<tr>
<td>SIMRAC</td>
<td>Safety in Mines Research Advisory Committee</td>
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</table>
STS : Standard Threshold Shift
T : Duration of measurement
\( t_0 \) : Time of observation (Instantaneous time)
TB : Tuberculosis
TLB : Tractor Loader Backhoe
TLV : Threshold Limit Value
TOR : Terms of Reference
TTS : Temporary Threshold Shift
TVM : Time Value of Money
TWA : Time weighted average
UK : United Kingdom
USA : United States of America
VDV : Vibration Dose Value
\( \text{vs} \) : Versus
VWF : Vibration-induced White Finger
WB : Whole-body
WBV : Whole Body Vibration
WHO : World Health Organisation
\( \tau \) : Integration time for running averaging
# 5 KEY DEFINITIONS

| **HEG** | Means a group of employees who experience noise exposures similar enough that monitoring exposures of any representative subgroup of employees in the group provides data useful for predicting exposures of the remaining employees. |
| **L_{Aeq}**: | The A-weighted, equivalent continuous sound level in decibels measured over a stated period of time, $L_{Aeq,T}$ where $T$ is the measurement time. Most community and industrial noise measurements are A-weighted so the $L_{Aeq}$ descriptor is widely used. |
| **L_{eq}**: | The equivalent continuous sound level in decibels, equivalent to the total sound energy measured over a stated period of time and is also known as the time-average sound level (LAT). |
| **Peak Sound Level** | The greatest instantaneous value of a standard-frequency-weighted sound pressure level, within a stated time interval, and is also known as the peak frequency weighted sound pressure level. IEC 801-22-15. If frequency weighting is not specified, the A-frequency weighting is understood. |
| **Present Value of Future Costs** | This is the value of all future expenditure, expressed in "todays" terms. |
| **Relevant Costing** | Relevant costing is a decision-making tool which looks at the financial implications of making a certain decision. In this particular study, the relevant cost therefore represents the costs which are only incurred as a result of noise exposure. |
## 6 OVERALL PROJECT SUMMARY

Table 1: Overall Project Summary

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<th>What was planned for the Milestone?</th>
<th>Was it achieved?</th>
<th>Any deviations?</th>
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<td>✓</td>
<td>none</td>
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<tr>
<td><strong>Milestone 2</strong> Literature Review on Mining Noise and Vibration Exposure</td>
<td>✓</td>
<td>Submitted 07 April 2020 vs. 29 February 2020 deadline</td>
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<tr>
<td><strong>Milestone 3</strong> Determination of the Impact of Current Noise OELs on Employees</td>
<td>✓</td>
<td>Submitted 2 months after initial deadline (extension requested and granted)</td>
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<tr>
<td><strong>Milestone 4</strong> Determination of the Impact of Vibrations on Employees</td>
<td>✓</td>
<td>Submitted 2 months after initial deadline (extension requested and granted)</td>
</tr>
<tr>
<td><strong>Milestone 5</strong> Review of Relevance and Applicability of Current Noise and Vibration OELs</td>
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<td><strong>Milestone 6</strong> Development of Proposed Noise and Vibration OELs and Associated Guidance Note</td>
<td>✓</td>
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<tr>
<td><strong>Milestone 8</strong> Final report (approval)</td>
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<td>Submitted 10 days after deadline</td>
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</table>
7 EXECUTIVE SUMMARY

This project is structured into five main phases:

- Review the literature on mining noise and vibration exposure.
- Determine the impact of current noise OELs on employees.
- Determine the impact of vibrations on employees.
- Review of relevance and applicability of current noise and vibration OELs.
- Develop proposed noise and vibration OELs with associated guidance notes.

This final report contains the findings from all of the above phases.
## 8 OVERALL PROJECT AIMS AND OBJECTIVES

The overall project aims and objectives can be seen in Table 2, as per the original project proposal.

**Table 2: Overall Project Aims and Objectives**

<table>
<thead>
<tr>
<th>WHAT ARE THE EXPECTED RESEARCH OUTCOMES</th>
<th>HOW WILL THE RESEARCH OUTCOMES IMPROVE HEALTH AND SAFETY IN SOUTH AFRICAN MINING INDUSTRY?</th>
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</thead>
</table>
| - Conduct a literature review on mining noise and vibration exposure and compare the SAMI’s noise OEL with other countries’ standards.  
- Conduct a study to determine the impact of the current noise OELs on employees’ hearing capability.  
- Conduct a study to determine the impact of vibrations on employees, based on current mining operations.  
- Review the relevance and applicability of the current noise and vibration OELs including the classification bands in terms of risk.  
- Develop a guidance note to propose potential OELs for noise and vibration to be used in the SAMI with consideration of potential barriers. | For the most part, the workplace contributes the greatest dose of daily noise for workers in the mining industry. Therefore, without effective legislation to protect workers from harmful levels of noise, thousands of people in South Africa will suffer permanent occupational related hearing loss. Another pervasive phenomenon is vibration, which is known to have adverse effects on the human body. Severe pain and the so-called Raynaud’s syndrome (“white finger” syndrome), which damages blood vessels and nerves, are known health outcomes.  
To effectively manage these health outcomes, it is necessary to determine whether current legislation is adequate and aligned with international standards. The investigation will therefore also reveal current international best practices and international legislation and the studies that helped shape the legislation. |

<table>
<thead>
<tr>
<th>HOW SHOULD THE RESEARCH OUTCOMES BE IMPLEMENTED?</th>
<th>NAME THE CHAMPION MINE (S) THAT WILL BE USED IN THIS RESEARCH</th>
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<tbody>
<tr>
<td>By investigating the current local legislation and its effectiveness, in conjunction with international legislation and studies, the study will be able to make quantitative recommendations for the next generation of legislation, in terms of exposure limits for noise and vibration. Communicate the guidance note on the proposed potential OELs for noise and vibration throughout the SAMI and update the regulation related to the MHS Act and South African Mines Occupational Hygiene Programme.</td>
<td>Sibanye Gold Mines and Anglo American Platinum Mines but not limited to the mentioned mining companies</td>
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## 9 PROJECT SCHEDULE

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<td>2 Literature Review on Mining Noise and Vibration Exposure</td>
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<td>3 Determination of the Impact of Current Noise OELs on Employees</td>
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<td>4 Determination of the Impact of Vibrations on Employees</td>
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<td>6 Development of Proposed Noise and Vibration OELs and Associated Guidance Note</td>
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<td>7 Draft final report (submission)</td>
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![Figure 1: CoE 180701 Project Schedule]
## 10 PROJECT FINANCES

Table 3: Project Finances

<table>
<thead>
<tr>
<th>No.</th>
<th>Milestone</th>
<th>Milestone Timelines</th>
<th>HR Costs</th>
<th>Operating Costs</th>
<th>Capital Costs</th>
<th>Sub-Contractor Costs</th>
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<tr>
<td>1</td>
<td>Project initiation</td>
<td>11/19 11/19</td>
<td>R209 360,00</td>
<td>R 15 702,00</td>
<td>-</td>
<td>-</td>
<td>R225 062,00</td>
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<td>2</td>
<td>Literature Review on Mining Noise and Vibration Exposure</td>
<td>11/19 02/20</td>
<td>R325 500,00</td>
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<td>Determination of the Impact of Vibrations on Employees</td>
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<td>R112 531,00</td>
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<td>8</td>
<td>Final report (approval)</td>
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<td>R209 360,00</td>
<td>R 15 702,00</td>
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<td>R225 062,00</td>
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PART 1 | INTRODUCTION
11 INTRODUCTION & BACKGROUND

11.1 BACKGROUND

The insidious and cumulative nature of noise induced hearing loss (NIHL), as well as recent studies indicating potential NIHL below 85dB(A) suggested a review of the occupational exposure limit (OEL) of noise in South Africa. At the same time South Africa also does not currently have OELs for vibration. This is not aligned with international best practice.

The Mine Health and Safety Council (MHSC) therefore contracted Enterprises University of Pretoria to review the current SAMI noise exposure limit and conduct a study to explore the desirability of OELs for vibration in the SAMI.

The outcome of this study is intended to support the MHSC in making recommendations pertaining to noise and vibration OELs to the minister of Minerals Resources and Energy. These recommendations are intended to improve occupational health and safety conditions in the South African Mining Industry (SAMI).

In 2019 the SAMI employed 454 861 employees (Mineral Council South Africa Integrated Annual Report, 2019) across all commodities. These employees work in different mining environments, under different conditions and according to different work schedules, where they are exposed to different environmental stressors.

Noise and vibration are two of these stressors and are categorised as so-called physical environmental stressors.

Exposure to such physical stressors is known to cause detrimental health effects:

- Noise can cause auditory effects such as noise induced hearing loss (NIHL) and non-auditory effects such as adversely affected communication, elevated heart rates and increased annoyance. There is also evidence that exposure to noise is a contributing factor for the development of hypertension and diabetes (Schoeman and Van den Heever, 2015).
- Hand-arm vibration can lead to Raynaud’s disease which can cause severe pain and discomfort (Griffin, 1990).
- Continuous excessive whole-body vibration may cause musculoskeletal injuries and adverse kidney effects (Griffin, 1990).

Although it is generally accepted that an OEL is a “safe” level of exposure to which workers could be exposed to on a daily basis for their entire working life without becoming ill, the occurrence of occupational disease remains high. The subsequent compensation and administrative costs, as well as the associated penalties, warrant a regular revision of OELs.

It is believed that OELs in the SAMI may need to be amended to reflect specific South African environmental conditions and population characteristics. The work schedules of different mines may also influence the specific exposure limits that must be implemented.

One of the significant risks associated with noise, whole-body vibration and hand-arm vibration exposure is that the health effects are initially unnoticed and generally develop gradually. It is presumed that in many cases, workers may only experience the full brunt of work related NIHL, WB- and HA vibration exposure, once they retire from work. Some occupational related
diseases only start to manifest in general 15 to 40 years after continuous excessive exposure. This course of things is also quite typical of noise and vibration exposure.

This project addresses the desirability of changing the current SAMI noise exposure limit. It also addresses the need for setting vibration exposure limits for the SAMI.

In structuring the project, five main milestones were set. These milestones are schematically depicted in Figure 2.

**Figure 2: Project Flow**

The report is structured in four parts:

- **Part 1** presents a general introduction to noise and vibration in the South African mining industry. It also provides a general introduction to occupational exposure limits, their origins, underlying principles, limitations and processes related to amending OELs.

- **Part 2** presents the results of the literature review on mining noise exposure. It then continues with the determination of the impact of current noise OELs on employees in the mining industry. This is followed by a review of the relevance and applicability of current noise OELs and finally by proposed changes the noise OELs. An associated guidance note for noise is also proposed.

- **Part 3** follows the same general pattern as Part 2 but considers OELs for whole-body vibration and hand-arm vibration. Firstly, the results of a literature review on exposure to vibration in the mining industry is presented. This is followed by an analysis of the impact of vibration on employees in the mining industry. Subsequently a review is conducted of the relevance and applicability of current noise OELs. Lastly new OELs are proposed for whole-body vibration and hand-arm vibration in the SAMI. Associated guidance notes for whole-body vibration and hand-arm vibration are proposed.

- **Part 4** presents the conclusions and recommendations of this work.

### 11.2 An Introduction to Noise and Vibration in the SAMI

Noise is usually defined as unwanted sound. It is caused by tiny pressure fluctuations that propagate through the air at the local speed of sound and finally impinges on the human ear, where the pressure fluctuations are then passed on to the auditory nerve, through an intricate biomechanical system.
Pressure disturbances like these are very commonly caused by vibratory surfaces which set air particles adjacent to these surfaces in motion. It may also be caused by high speed flow of air that causes turbulent mixture of air streams and subsequent fluctuation in air pressure.

Typical examples of noise sources in the mining industry are vibrating surfaces such as pipes or ducting, vibrating screens or machine casings which are set in motion by rotating machinery. Fans and compressors, as well as leaking valves and high-pressure air lines, are examples of cases where moving air cause disturbances in air pressure.

Vibration does however not only set air particles in motion which is then perceived as noise through the auditory nerve but may also directly be transmitted to the human body. This usually happens via the feet of standing people or buttocks of sitting people. This type of vibration transmission causes the entire human body to vibrate and is known as whole-body vibration. The case where vibration is transmitted through the human hand is known as hand-arm-vibration.

Vibration that is transferred to the human body in this way often cause resonance of body parts which may interfere with normal bodily functions (such as sight) due to excessive motion. It may also lead to high stress in the spine and in joints, as well as cause a variety of other disorders.

Whole-body vibration in the mining industry is very typically encountered when vibration is transferred from a moving vehicle such as a truck or mining machine, through the operator seat and through the operator’s feet on the vehicle floor.

In the mining industry hand-arm vibration is very commonly encountered when equipment such as rock drills are handled by operators and high levels of vibration are transferred to the human body via the operator’s hands. Other typical examples include handheld machinery used in workshops at mines.

Because of the potentially detrimental effects of these stressors on the human body, the Mine Health and Safety Act No. 29 of 1996 requires appropriate risk assessment to manage the significant risks to prevent adverse health effects. The risk assessment must prioritise the risks to be addressed and inform management on actions to be taken. Such actions for example include occupational hygiene surveys and appropriate medical surveillance to be conducted, as well as the re-training of personnel in terms of controlling noise using the hierarchy of control principles.

For context, processes related to noise were considered in some detail, namely:

- Occupational Hygiene Surveys;
- Medical Surveillance;
- Operational Challenges;
- Non-Compliance; and
- Factors that distinguish South African mining from typical international conditions.
11.3 DEVELOPMENT OF OELs FOR NOISE AND VIBRATION

11.3.1 A Brief History of Occupational Exposure Limits

The development of OELs is often traced back to work by the German scientist, Max Gruber, who published reports on the effects of carbon monoxide at varying air concentrations on himself and on laboratory animals in 1883 (Borak and Brosseau, 2015).

In the United States of America, the first compilation of exposure limits was published in 1921 by the Bureau of Mines, which described odour and irritation thresholds of a range of substances that were frequently encountered in mines and workplaces (Borak and Brosseau, 2015). This work, amongst others, laid the foundation for a committee of the American Conference of Governmental Industrial Hygienists (ACGIH) to develop and disseminate comprehensive lists of scientifically based exposure standards for chemical substances. A systematic collection of OELs for chemical substances was subsequently published in 1946.

These OELs were generally much less protective, relatively informal and more risk-tolerant than their current counterparts. They do however represent a great step forward towards industrial hygiene and a landmark in the thinking with respect to worker protection. While occupational health limits are nowadays considered important, significant hurdles remain to be overcome (Borak and Brosseau, 2015):

- An important hurdle to the development of OELs is the lack of data that are specifically relevant to human exposures in occupational settings.
- A second hurdle relates to the harmonisation of the development, selection and application of OELs.
- A third problem in this regard is the lack of systematic approaches in the development of OELs in the context of lacking data and inadequate global harmonisation.

In South Africa the standards and legislation to control noise exposure uses the term “noise rating limit” and not OEL to describe the level of exposure that may result in occupational NIHL. The “noise rating limit” as defined in the Noise Induced Hearing Loss Regulations refers to “the value of the 8-hour rating level, 85 dBA at and above which hearing impairment is likely to result”. Exposure of an employee to noise levels of ≥ 85 dB(A) is considered as non-compliant.

For whole-body and hand-arm vibration, it is common to introduce so-called exposure action levels and exposure limits values. This approach is also adopted in this report.

The terminology of occupational exposure limits is however still used as a general concept to refer to limits on safe noise and vibration levels.

11.3.2 The Occupational Exposure Limit Landscape

Occupational exposure limits are important for the interpretation of workplace stressor exposures in the health risk context (Deveau, et al., 2015). Since their introduction, the use of OELs has enjoyed widespread uptake (Deveau et al., 2015). However, the proliferation of OEL setting bodies, all confronted with the challenges of evaluating and interpreting large amounts of complex scientific evidence, has yielded a confusing landscape of OELs. Occupational hygienists are therefore often confronted with various relevant, but conflicting, OELs for specific situations. This is not ideal since it may lead to duplication of work and effort.
It is important to note that OELs are generally set for an 8-hour workday, 40 hours a week (ACGIH TLVs® and BEIs, 2019). The ACGIH (2019) makes it clear that careful judgement needs to be applied when the workday extends beyond 8 hours. This is because some employees are exposed to additional noise sources outside their normal employment and that may lead to an over-exposure if re-calculated to an 8-hour exposure, and recovery time of employees between shifts becomes less. The ACGIH therefore advise that extrapolation of OELs when employees are exposed for periods longer than 8-hours needs to be done with great caution.

Due to the variation in noise exposure during a normal workday, the Time-Weighted Average is calculated. Time weighted average for noise is calculated using the following formula:

\[
TWA (8 hrs) = \frac{x_1.t_1 + x_2.t_2 + \ldots + x_n.t_n}{8}
\]

Where
- \(x\) = exposed noise level in dB(A)
- \(t\) = exposure time in hours

OELs are applicable to the working environment and are not adapted, considering other exposures outside of the working environment. The fact that many employees partake in hobbies or recreational activities/sport which exposes them to high levels of noise, is often not disclosed when medical evidence of a deterioration in health is gathered. This can also be the case where employees are exposed to other stressors outside the working environment, where exposure is similar to the occupational exposure.

11.3.3 Principles for the Development of OELs

Deveau et al., (2015) present several ideal characteristics of standardised scientific supporting documents for OELs. Although these principles are formulated in the context of chemical exposure limits, it is believed that the characteristics below are also relevant to physical stressors:

- Reflects current knowledge as presented in the scientific literature.
- Includes recent publications that have been peer reviewed.
- Communicates approaches and resulting OELs openly and transparently.
- Is developed by a scientific committee consisting of independent scientists.
- Presents and scrutinizes all relevant epidemiological and experimental studies.
- Presents and scrutinizes environmental and biological monitoring possibilities.
- States and describes the establishment of dose-response and dose-effect relationships.
- Identifies the critical effect (the effect that appears at the lowest exposure level) along with reasons as to why a certain effect is the critical one.
- Provides a comprehensive reference list.

If the above principles are effectively applied, similar OELs may be set in different countries. Deveau et al. (2015) reported however that different approaches are used by OEL-setting organisations due to the nature of the risk assessment applied and gaps that exist in data.
The Regulations for Hazardous Chemical Substances Annexure 1 stipulate three conditions to be considered for setting of OELs namely:

- There is no-risk at the exposure limit,
- Likelihood of excursions above the exposure limit, and
- Practicability of compliance is reasonable.

These principles should always be applied, regardless of the type of environmental stressor (factor). Scientific evidence needs to be found to establish that there will be no health risk (effects) when employees are exposed day after day to a certain dose or exposure level over a reference period. It is however important to obtain evidence that compliance with the set OEL will be reasonably practicable.

The likelihood that excursions will take place above the set limit also needs to be considered and there must be evidence that excursions will not result in serious short or long-term health effects. Effect on the sensory-neural system also needs to be taken into consideration as changes in, for instance, reflexes may have an impact on safety aspects in the work environment. If there is evidence that it is unlikely that excursions above the set OEL will not cause serious short or long-term health effects, it is considered as reasonable to expect a company to identify and implement control measures to lower dose/exposure level to below the set exposure limit.

If there is evidence that exposure to the set level results in health effects, a stricter OEL needs to be assigned. This also applies if short and long-term health effects are associated with excursions above the set OEL. It is important to note that a stricter OEL in this context means that a smaller numerical value will be required e.g., a change from 90 dBA to 80 dBA.

The socio-economic status of a country also needs to be taken into consideration with the setting of OELs. If it is reasonably practicable to implement controls to lower the exposure levels of a specific stressor i.e., by implementing equipment that generates lower noise levels and/or lower levels of vibration, a stricter OEL can be set to decrease the likelihood of developing occupational diseases associated with exposure to the specific stressor.

Reasonably practicable considers the severity and scope of hazard (risk), knowledge available on hazard or risk, availability, and suitability of mitigation (control) measures and cost of the latter. However, arguments by the Occupational Health and Safety Administration (OHSA) in the United States that lower OELs would be “better” or reduce the risk was rejected by the US Supreme Court (Rose, 2003), who stipulated that the reduction of the risk must be quantified.

### 11.3.4 Limitations of OELs

It is appropriate to consider the definition specifically of TLVs® as it clearly describes “a condition to which nearly all employees could be exposed without adverse effect”. An OEL must therefore be seen as a level of exposure that does not guarantee that all employees would be protected at all times.

The physiological, psychological, and nutritional state of an employee is also important, as the premise of OELs is that employees are healthy and are on a healthy diet. This is however not true for many employees (Deveau et al., 2015). Furthermore, individuals may change anatomically (gain or lose weight) and physiologically (become pregnant) or an employee could develop a disease, which could make the employee more vulnerable. In such instances
the OEL is not be protective in any manner. OELs are applicable to the working environment and cannot automatically be used as the “safe” (healthy) level of exposure in a general environment.

11.3.5 Financial Implications of Amending OELs

Amending OELs may result in a huge cost burden due to the processes required to be followed as described previously. The involvement of the state representatives, employer representatives and representatives of organised labour in the South African context may increase the time to reach a final decision on what the amended level needs to be. It took approximately four years to reach an agreement and to implement the new OEL for CO (from 50 ppm to 30 ppm) in the mining industry. The amendment and implementation of crystalline silica (from 0.4 mg.m⁻³ to 0.1 mg.m⁻³) went much faster as directives to this effect were issued.

The ACGIH TLVs® are amended annually. These changes are communicated with the Booklet on Threshold Limit values for Chemical Substances and Physical Agents (Howard, 2005). The process for adopting a new or revising an existing TLVs® can take a minimum of two years.

The Occupational Health and Safety Administration (OSHA) does not update their permissible exposure limits (PELs) annually. A first attempt to update the 1971 PELs for chemicals, was made in 1989 (Howard, 2005). This was however not successful.

In this work cost models relevant to the South African situation were developed for the change or introduction of OELs. These models are discussed in detail in Parts 2 and 3 of the report.

11.3.6 Process to be Followed to Amend Noise and Vibration OELs

The general approach followed to amend OELs is to involve experts in the specific field of interest, to scrutinise literature that report exposure levels in industry and health effects associated with exposure to the specific stressor. Focus is usually only on the health effects that are considered when considering compensation.

Health effects other than the classical occupational health effects usually considered when submitting a claim for compensation, need also to be considered as this may have an impact on well-being and general quality of life. This is usually not considered during compensation claims although it may have a significant impact on well-being and general quality of life. Considering health effects not considered for compensation purposes, may however have a cost/financial impact because the set limit may need to be lowered to a value lower than when only the primary health outcome is considered. Figure 3 depicts the process that is followed in Poland to set specific standards whereas Figure 4 illustrates how the Government of South Africa manages Occupational Health and Safety in the mining industry. The Government has the authority and responsibility to ensure that all employees work in a healthy and safe environment and employers (mines) have a policy and comply to certain Codes of Practice, Standards and OELs.
One of the eight basic rights of a South African employee is the right to protection of his/her safety and health at the workplace. This right was acknowledged by the South African government in a policy statement in the Manpower 2000 Manifesto. The Mine Health and Safety Act which was promulgated on 14 June 1996 uses Tripartite institutions to advise the Minister of Mineral Resources and Energy on health and safety issues at the mines.

The Mine Health and Safety Council is the turnkey institution to advise the Minister of Mineral Resources and Energy on various aspects pertaining to health and safety at mines, including...
the setting of OELs. The Mine Health and Safety Council makes use of three permanent advisory committees:

- Mining Regulatory Advisory Committee (MRAC).
- Mining Occupational Health Advisory Committee (MOHAC).
- Safety in Mines Research Advisory Committee (SIMRAC).

The different Advisory Committees advise the Council on:

- Regulatory matters (legislation, changes to legislation, guidelines for Codes of Practices and Standard).
- Occupational health related issues (health policy, standards, systems and procedures to ultimately minimise health risks, regulations on health, health research and collecting, processing and distribution of health data to industry).
- Research matters (criteria for funding research, the need of research, the management of research projects, communication and publication of research and the management of the costs).

Thus, MOHAC would be responsible for proposing OELs (including noise and vibration) in collaboration with the other advisory committees. MOHAC, with the other advisory committees and other organisational and professional bodies are responsible for proposing and/or revising OELs. However, before revised- and/or new OELs are promulgated various processes of publication, notice of intended changes (usually 90 days) are given, workshops and comments are called for. Once the Council have gone through all the prescribed processes of rework and consultation, the Council will approve the OELs. The MHSC will mandate the MRAC and the Legal Drafting Committee (LDC) to review the proposed changes from a legal perspective. The LDC consists of lawyers from the State, Minerals Council and Organised Labour. After LDC and MRAC have completed their reviews the Minister of Mineral Resources and Energy will be advised and the OEL would be promulgated under the applicable Regulations.

Note: Where reference is made to OELs it applies to all guidelines, standards, etc.

A new or revised OEL must be practicable and be able to be achieved in the time period allocated therefore and the technology and/or knowhow must exist to achieve the compliance.
PART 2 | NOISE
12 LITERATURE REVIEW – NOISE

A comprehensive literature review was conducted in this project. Salient aspects of this report are summarised here under the headings shown in Figure 5.

Figure 5: Literature Review - Noise Overview

12.1 EXISTING LEGISLATION, STANDARDS AND OEL FRAMEWORKS FOR NOISE

12.1.1 Introduction

Approximately 50% (3.427 billion labour force out of a total 7.594 billion total population) of the world’s population work (The World Bank, 2020). Half of these workers are exposed to noise. Millions of these workers are excessively exposed to noise daily.

In South African 80% of the total number of workers in the mining industry were exposed to noise in 2017 (Department Mineral Resources, n.d.), of which 66.17% were over-exposed (Band A and Band B). Although continuous improvement ("road to zero harm") is the highest priority regarding health and safety, the then DMR reported only a 3% decrease in occupational disease between 2016 and 2017 (Department Mineral Resources, nd). The majority of the diseases are Pulmonary Tuberculosis, NIHL and Silicosis.

Based on the research of the European Agency (European Agency for Safety and Health at Work. 2005), a rough estimate is that approximately 25 to 30% of all employees are exposed to excessive noise, except for Hungary (2003) where only about 10% of the workers were exposed to noise. Germany is the only country that showed a decrease in the number of workers (until 1999) exposed to noise.

Arenas and Suter (2014) estimated that more around 20.1% of the Australian workers are excessively (85 dBA) exposed to noise. The WHO (World Health Organization, 2004) found that in the Americas (Latin America, USA and Canada) more than 300 000 disability-adjusted life years were lost due to NIHL.

Bauer et al. (2001) indicted that NIOSH reported in 1996 that NIHL was the most common occupational disease in the USA at the time, with 30 million employees being excessive exposed to noise. According to Bauer et al. (2001), Franks indicated in 1996 that 70% to 90% of the miners experience a loss great enough to be classified as a hearing disability. In their report on Technology for a Quieter America, the National Academies of Sciences, Engineering and Medicine (2010) state that noise exposures and incidence of hearing impairment are higher than average among miners and that according to NIOSH, most drill operators over 40 years of age suffer NIHL.

12.1.2 Legislative review

The mining industry in South Africa is governed by the Mine Health and Safety Act, Act 29 of 1996 (Mine Health and Safety Act, 1996). As stipulated in Section 8.1(b) and (c) of the Mine
Health and Safety Act the employer must establish a policy concerning the protection of employees’ health and safety at work, and persons who are not employees but who may be directly affected by the activities at the mine.

Regarding the management of the risks to which employees are exposed the employer must:

- Identify the hazard to health or safety.
- Assess the risks to health or safety and regularly review the identified risks and its assessment.

The employer must ensure that the significant hazards and risks identified are recorded and that those records are made available for inspection by employees.

The employer, must after consulting the health and safety committee at the mine, determine all measures, including changing the organisation of work and the design of safe systems of work so as to eliminate any identified risk, or control the risk at source or must minimise the risks. In so far as the risk remains, the employer must provide for personal protective equipment and institute a programme to monitor the risk to which employees may be exposed. The employer must implement the measures determined necessary insofar as it is reasonably practicable to do so, in the order of priority.

All employers with any of the above-mentioned as significant risks must compile a Code of Practice, which need to be submitted to the regional Director of the DMRE. Such a Code of Practice must comply rigorously with specific guidelines issued by the chief inspector. The employer must deliver a copy of every code of practice prepared to the chief inspector. Cognisance should be taken of the fact that the DMRE has promulgated the compilation of Mandatory Code of Practices, of which noise is one.

The Mine Health and Safety Act stipulates that as far as it is reasonably practicable, every employer must:

- Provide employees with any information, instruction, training (before commencement, at regular intervals and when changes occur) or supervision that is necessary to enable them to perform work safely and without risk to health (including the elimination, minimising and controlling of the risks) of the employee (Section 10.(1)(a)).
- Cause every employee to be made conversant with work-related hazards and risks, as well as the measures that must be taken to eliminate, control or minimise those hazards and risks (Section 10.(1)(b)).

In terms of occupational hygiene, the employer must:

- Engage a person qualified in occupational hygiene techniques to measure levels of exposure to hazards and/or risks at the mine and to keep a record thereof (Section 12.(1)).
- Use appropriate measurements (Section 12.(2)(a) to provide information that assists the employer to eliminate, minimise or control the health risks and hazards to which employees are or may be exposed. (Section 12.2(b)).

The measurement programme (Department Minerals and Energy, 2002) is based on the Classification Band, within which the sound level falls, of the particular HEG or SEG and strict guidelines are provided in terms of the frequency of measurement as well as the number of
employees. A summary of the requirements as well as when a hearing conservation programme needs to be implemented are provided in Table 4.

Table 4: Noise sampling and control strategy

<table>
<thead>
<tr>
<th>Level of exposure</th>
<th>Classifications bands</th>
<th>Sampling frequency per HEG</th>
<th># of employees</th>
<th>Control strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥105 dB</td>
<td>A</td>
<td>Annually</td>
<td>5% of employees (minimum 5) equally distributed</td>
<td>Hearing conservation programme</td>
</tr>
<tr>
<td>≥85 dB but &lt; 105 dB</td>
<td>B</td>
<td>Annually</td>
<td></td>
<td>Hearing conservation programme</td>
</tr>
<tr>
<td>≥82 dB but &lt; 85 dB</td>
<td>C</td>
<td>Bi-annually</td>
<td></td>
<td>N/A</td>
</tr>
</tbody>
</table>

Subsequent to assessing the risks the employer has the obligation to establish and maintain a system of medical surveillance of employees exposed to health hazards if required to do so by regulation or by a notice in the Government Gazette and if it is necessary to do so after assessing risks.

Every system of medical surveillance must employ an Occupational Medical Practitioner part-time or full-time, who needs to ensure that the medical surveillance programme is:

- Appropriate, considering the health hazards to which the employees are or may be exposed.
- Designed so that it provides information that assists the employer to eliminate, minimise or control the health risks and hazards to which employees are or may be exposed.
- Designed to assist the prevention, detection, and treatment of occupational diseases.
- Consist of an initial medical examination and medical examinations at appropriate intervals (pre-employment and periodical examinations) and keep all records pertaining thereof.

If any employee is declared unfit to perform work as a result of an occupational health disorder, the employer must ensure that an investigation is conducted. If an employee is temporarily unfit to perform work as a result of any occupational health disorder, but there is a reasonable expectation that the employee’s health will improve so that the employee can return to work, the occupational medical practitioner must record and notify both the employer and employee of this fact.

12.1.3 A Review of Standards

The South African national standards related to noise are presented in Table 5. The standard relevant to this project is the measurement and assessment of occupational noise for hearing conservation purposes and the measurement of noise emitted by motor vehicles.

It is important to take cognisance of the fact that SANS Code of Practice 10083 (2013) does not only deal with noise monitoring but also medical surveillance and specifically audiometry.

Table 5: Standards that are potentially relevant to noise in a mining environment

<table>
<thead>
<tr>
<th>Description</th>
<th>Code No.</th>
<th>Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>The measurement and assessment of occupational noise for hearing conservation purposes</td>
<td>SANS 10083</td>
<td>2013</td>
</tr>
</tbody>
</table>
Internationally there are numerous standards of which the most important ones, specifically applicable to the literature review are:

- ISO 1996-1:2016 Description, measurement, and assessment of environmental noise
  – Part 1: Basic quantities and assessment procedures
- ISO 1996-2:2017 Description, measurement, and assessment of environmental noise
  – Part 2: Determination of sound pressure levels

### 12.1.4 International OELs

During the review of international noise OELs, the following were taken into account:

- Americas (excluding the United States of America);
- United States of America; and
- European Union and the United Kingdom.

### 12.1.5 A review of OEL frameworks

The goal of the review of OEL frameworks is to provide guidelines for setting or proposing a revised OEL for noise, if practicable.

Following a comprehensive literature survey, Concha-Barrientos, Campbell-Lendrum and Steenland (WHO, 2004) concluded that the best characterized health outcome for occupational noise is hearing impairment. The first effect of the exposure to excessive noise is typically an increase in the threshold of hearing as assessed through audiometry.
premise for setting a noise OEL would thus be audiometric evidence of a threshold shift. Previously a threshold shift was determined by the shift in hearing of an average of 10 dB or more in the 2, 3 and 4 kHz frequency bands in either ear (poorer ear). However, since 2008 the calculation includes the shift at 500 Hz and 1 kHz. The National Institute for Occupational Safety and Health (NIOSH) revised their threshold shift to 15 dB in 1998 and now also includes 6 kHz in the calculation.

Concha-Barrientos, Campbell-Lendrum, and Steenland, (WHO, 2004) consider a threshold shift as a precursor to NIHL (WHO, 2004). The International Labour Organisation (ILO) supports this view and stipulates that the noise limits should be function of the ultimate goal and refer specifically to:

- Prevent hearing impairment.
- Avoid interference with communication for safety purposes.
- Eliminate nervous fatigue (anxiousness) regarding work to be done.

The degree of protection would thus determine the OEL, however the ILO recommends that more than one limit should be determined, and suggested a:

- Warning limit where there is little risk of hearing impairment, with no protection for an 8-hour exposure period.
- Danger limit above which hearing impairment and deafness may occur, with no protection for an 8-hour exposure period.

NIOSH’s selection of an OEL is based on two parameters:

- Maximum acceptable occupational hearing loss.
- Percentage of occupational noise-exposed population for which the maximum acceptable NIHL will be tolerated.

A method to calculate the expected permanent threshold shift based on the level and duration of exposure is provided in the ISO 1999 Standard (2013).

### 12.2 SOURCES OF NOISE IN THE MINING INDUSTRY

Mining in the SAMI ranges from shallow to very deep underground mining, surface mining, as well as surface activities (e.g. workshops) to support underground and surface mining activities. This requires a wide range of mining equipment and related techniques. The different types of strata, from soft to hard rock, add a further dimension to the type of equipment required to effectively mine the different commodities. As a result, excessive noise levels are generated during day-to-day mining operations in the SAMI. Due to the challenge to control noise in the SAMI and high levels of reported NIHL cases in the SAMI, strategies to lower the prevalence of NIHL cases in the SAMI were discussed at a summit held in 2003. The following milestones were set at the summit:

1. Deterioration in hearing >10% must be reported in occupationally exposed individuals after December 2008.
2. The total noise emitted by equipment in any workplace must be <110 dBA.
3. Individual mining equipment noise levels must also be <110 dBA (Dekker et al., 2011).
An operational outcome of the summit was that mines had to generate an inventory of all the equipment that generate noise and indicate the measured noise levels of each piece of equipment.

A follow-up Occupational Health summit was held by the MHSC in September 2014 where new milestones were set. These milestones were (Mine Health and Safety Council, 2015):

1. Quietening equipment: By December 2024, the total operational or process noise emitted by any equipment must not exceed a milestone sound pressure level of 107 dB(A). (This milestone of the sound pressure levels will be verified by initiatives under the Centre of Excellence (CoE) and Mine Occupational Safety and Health (MOSH) initiative and reviewed in 2016).

2. Medical surveillance: By December 2016, no employee’s Standard Threshold Shift (STS) will exceed 25 dB from the baseline when averaged at 2 kHz, 3 kHz and 4 kHz in one or both ears.

To assist the SAMI to reach the set milestones it is imperative to scrutinise occupational hygiene survey data and other research projects that investigated noise levels in the SAMI to develop a proper understanding of the exposure levels of employees in the SAMI. This is also required to establish if additional approaches such as amending the noise rating limit needs to be amended, or if implementation of administrative control procedures will be required to reduce the STS of employees in the SAMI to below 25 dB from the baseline. This baseline is found by averaging at 2 kHz, 3 kHz and 4 kHz in one or both ears, as stipulated in the September 2014 Occupational Health summit document of the MHSC.

Several investigations pertaining to noise in the SAMI were conducted in order to understand specific contributions made by these studies.

### 12.3 Occupational Exposure to Noise

Noise – due to the nature of mining activities – is an inherent risk. The use of explosives and crushing of rock was introduced since the start of the industrial revolution and remain the primary noise sources. Recently, with advances in technology and pressure to produce more tonnage of ore during a work shift; pneumatic, electrical and diesel driven equipment is utilised to reach the set targets. The increase in diesel driven engines and the need to re-enter mines after blasting requires increased ventilation in underground mines. This requires the application of bigger fans to meet the ventilation requirements. Additional booster fans to supply enough ventilation are also required to supply sufficient air to development ends of a mines. The application of the above-mentioned equipment results in noise levels above the regulated noise level of 85 dB[L,A,8h] and peak sound level of 135 dB A in the SAMI. Noise exposure at and above the indicated levels are associated with occupational NIHL.

Local and international epidemiological evidence was assessed and found to be supporting of the association between noise exposure and NIHL.

### 12.4 The Development of a Noise Database

Noise data from the Safety in Mines Research Advisory Committee reports COL 714 (Heyns et al., 2001) and SIM 050501 (O’Brien et al., 2006) were utilised to develop an initial noise database.
12.5 **Noise Attenuation and Control**

Noise exposure is controlled by elimination, engineering techniques, administrative methods and the use of personal protective equipment. Noise reduction is complex and may impose enormous financial costs on a company and therefore careful consideration should be given to control options.

### 12.5.1 Elimination

Eliminating NIHL can be achieved during the design stage of a building, structure, machine, and equipment. However, it can in some instances come at high cost. Kovalchik et al. (2008) present an interesting case study on “designing out” noise in the mining industry. They consider the design process of a continuous miner. One of the concepts that they introduce is the coating of flight bars on the conveyor chain. Their quiet-by-design process results in a 3dB(A) noise reduction by considering four functional areas namely practice, policy, research, and education. A cost analysis indicated a 20% increase of the cost of the standard conveyor chain life but an extension of the conveyor chain life by a factor of 3. Taking a life cycle cost perspective during the design process is therefore also important and something which is very often not done in mining environments where buying decisions are often driven by purchase price.

If one considers the control of noise by eliminating excessive noise at the design stage one needs to consider aspects such as the structural dynamics of buildings and structures, the use and adding of damping material design and orientation and/or positioning of equipment it is vital to develop Codes of Practice, such as:

- Maximum allowed design noise criteria for all equipment and machines used at mines
- Structural orientation of accessories (e.g. valves and vents) and equipment (e.g. spacing between equipment)
- Use and application of acoustic material (absorbing-, barrier- and damping material)

Eliminating NIHL over time can be achieved by implementing a “buying quieter” policy and ensuring that the specifications of machines and equipment are well-thought through and included in tender documents (prescribed to procurement departments). This is however a policy which is probably very dependent on the extent to which noise regulations are enforced in practice.

### 12.5.2 Engineering Control

Engineering control measures are aimed at reducing the noise at the source or reducing noise on its transmission path between the source and the worker. This may be accomplished by the use of acoustic engineering techniques such as acoustic insulation, acoustic absorption, vibration isolation, damping screening, installation of silencers and mufflers, etc. (Peters et al., 2011). To ensure an effective noise reduction program, the principles underlying engineering control measures should be investigated and understood so that the correct measures can be applied. These techniques are generally well understood but not so often properly applied in the mining industry.
There is currently much work being done in the area of active noise control for industrial applications (noise cancellation or active noise reduction). The authors of the present report have however not found any convincing case studies where these techniques have been applied in the underground mining industry (it is highly likely that commercially products are used in surface mining operations.)

It is reasonable to suspect that while the installation of sensors on devices are becoming commonplace (e.g. smart mobile phones with built-in accelerometers and microphones), the mounting of cost effective microphones on active earmuffs might remain problematic in underground environments, partially due to humidity and dust ingress.

12.5.3 Administrative control

Administrative control should not be ignored and should assist the employer to better manage noise control efforts. Medical surveillance and specifically audiometry should be used to eliminate the employment of personnel that are at risk, as well as assisting the employer to manage employees that show a significant increase in hearing loss. Personal hearing protective devices (HPDs) are widely used for noise control, where engineering controls cannot reduce noise to an acceptable level and the use of HPDs rely heavily on the individual. Calculating the noise reduction rating (NRR) required or the use of supplied NRR should be verified and procurement and HPDs should be approved by a competent person. It is therefore key that HPDs are appropriate and workers are adequately trained in the use of HPDs. This training should be part of the induction (training and information) about the risks to which employees are exposed to, in this instance, specifically noise. Currently the training regarding risks (noise specifically) does not comply to legal guidelines.

12.5.4 Mechanised drill and blast and non-explosive mining

It is clear that rock drills represent a specifically problematic noise source in South African mines. In this regard a truly relevant study was commissioned by the MHSC as part of project SIM 050501 (Brink, et al., 2012). In this work the authors consider plasma drilling which is achieved by generating plasma by means of a high-energy electrical discharge through a medium such as water. This creates a shockwave that may break the rock under compression. They also consider ultrasonic rock drilling and rock breaking with very high frequency ultrasound. It is concluded that these technologies are not ready for industrialisation yet. They do however suggest that further work be done to replace the current mechanisms of pneumatic and hydraulic hand-held drills. In this regard they suggest a coil gun approach and a hydraulic sonic water-hammer. None of these techniques are currently ready for the market, and while it is believed that there is some potential for noise reduction, this seems to be a long way off. i.e. too far to influence 2020 thinking on the setting of occupational health standards.

Likewise, there is significant interest in alternative ways of non-explosive rock breaking. Techniques that are presently considered as part of the SAMERDI non-explosive rock breaking initiative ([https://www.csir.co.za/mining-and-mineral-resources](https://www.csir.co.za/mining-and-mineral-resources)) include diamond wire cutting and thermal spalling. These techniques are however also still in development and not ready for industrial application.
13 IMPACT OF CURRENT NOISE OELS ON EMPLOYEES

13.1 DATABASE STRUCTURE

For the systematic evaluation of the impact of noise and noise OELs on employees in the SAMI, a noise database was developed. The database compiled was subsequently enhanced by also including noise exposure and related data from the following sources:

- Detailed personal noise exposure measurements from a number of individual mines.
- Equipment noise levels reported by member mines to the Minerals Council South Africa (previously known as the Chamber of Mines of South Africa) (Deysel, 2020).
- Compensation data obtained from Rand Mutual Assurance Company Limited (RMA) (Kritzinger, 2020).

Analysis and interpretation from the data sources was conducted to determine the impact of the current noise OEL on employees’ hearing capability, by considering:

- If employees are exposed to occupational noise in excess of the OEL.
- If employees are contracting illness associated with exposure to occupational noise.
- If the illnesses contracted are relative to the noise exposures experienced by employees.
- The identification of potential reasons for such over-exposures (if any) in terms of noise source exposure, shift time, reporting method/s, etc.
- The financial implications of the current OEL.
- Potential technology available for the control on noise exposure.
- The perceived practicality of implementation of the current OEL.

13.2 PERSONAL NOISE EXPOSURE DATA REPORTED BY MINES TO THE DEPARTMENTS OF MINERAL RESOURCES AND ENERGY

The Mine Health and Safety Act (MHSA) requires mines to submit statutory reports on personal noise exposure monitoring results as stipulated in section 9.2.7 of the act.

These noise surveys must be conducted in accordance with the methodologies described in the mandatory noise code of practice (COP) when mining employees are exposed to noise levels of $\geq 82 \text{ dBA}_{eq,8h}$ (Mine Health and Safety Inspectorate, 2003).

The report format is prescribed in Chapter 21 of the MHSA as form 21.9(2)(e) (Republic of South Africa). It is required that mines report (among others) the following personal noise sampling information, per Homogeneous Exposure Group (HEG), on a quarterly basis to the DMRE:

- Names of Occupations in the HEG.
- Codes of Occupations in HEG.
- Number of persons per occupation.
- Logarithmic Average Sound Pressure Level ($L_{A_{eq,8h}}$) of all samples collected for each occupation.
- Total number of samples collected for the HEG.
- Logarithmic Average Sound Pressure Level ($L_{A_{eq,8h}}$) all samples collected for the HEG.

Form 21.9(2)(e) stipulates that the Logarithmic Average Sound Pressure Level ($L_{A_{eq,8h}}$) must be calculated as per formula on page 74 paragraph 3.6.2.2 of the MCOP reference number DME 16/3/2/4-A3, being:

$$L_{EX,W} = 10 \log \left( \frac{1}{5} \sum_{i=1}^{n} 10^{-0.1L_{EX,8h}} \right)$$

Where:
- $L_{EX,W}$ is the weekly average of daily values for LEX, 8h in decibels.
- $n$ is the number of days in the working week (normally 5), and
- $i$ is the number of sampling intervals per day (defined as 1).

The South African Mines Occupational Hygiene Programme (SAMOHP) Codebook (SAMOHP Section 2.3.3) defines three exposure categories and indicates the general action and personal exposure sampling frequency (SAMOHP Section 2.3.4) for each exposure category. These requirements are summarised as Table 6.

**Table 6: Summary of noise exposure categories and general action to be taken as stipulated in the SAMOHP codebook**

<table>
<thead>
<tr>
<th>Category</th>
<th>Personal Exposure Level</th>
<th>General Action</th>
<th>Minimum Monitoring Frequency</th>
<th>Monitoring Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Exposures $\geq 105$ dB $L_{A_{eq,8h}}$</td>
<td>Implement formal hearing conservation programme</td>
<td>Sample 5% of employees within a HEG on an annual basis with a minimum of 5 samples per HEG, whichever is the greatest.</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Exposures $\geq 85$ and $&lt; 105$ dB $L_{A_{eq,8h}}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Exposures $\geq 82$ dB $L_{A_{eq,8h}}$ and $&lt; 85$ dB $L_{A_{eq,8h}}$</td>
<td>No special precautions</td>
<td>Sample 5% of employees within a HEG on a two-yearly basis with a minimum of 5 samples per HEG, whichever is the greatest.</td>
<td></td>
</tr>
</tbody>
</table>

The South African Mining Industry Occupational Exposure Limit for noise is regulated in terms of regulation 22.9(2)(b) of the MHSA. It is regulated as being:

1. Noise Exposure: 85 dB$A_{eq,8h}$ and

The 85 dB$A_{eq,8h}$ relates to the maximum noise exposure that an employee might be exposed to for an 8-hour workday and a 40-hour work week. This exposure is obtained from full shift personal exposure monitoring. There is currently no requirement to report the Peak Sound Level to the DMRE.
The number of exposed employees per exposure category, as reported by the mines to the DMRE is summarised and presented as Figure 6. It is important to note that these exposures were assigned based on calculated average results for the HEG and not on individual sample results.

Figure 6: Summary of noise exposed employees per DMRE exposure reporting category (2014 to 2018) for the South African Mining Industry

Two sources of information were consulted in an effort to compare the number of noise exposed employees to the total number of employed employees. These sources consisted of:

- The Department of Mineral Resources and Energy, Mining Health and Safety Inspectorate Annual Reports covering the periods 2013 to 2017 (Summarised as Table 7). The 2019 report data were not yet available for release by the DMRE at time of compiling this report.

- Minerals Council South Africa, Facts and Figures 2018 indicated as Table 7.

It is evident that the two sources differ from each other in that the data presented in Table 7 (employees at work) is consistently lower than the data presented in Table 8 (employees at work).

This results as the DMRE Mineral Economics directorate collects and reports on two sets of mining employment, namely:

- Average number of employees at work (Table 7). This information is based on the number of employees who are physically on duty at a mining site, including employees contracted to the mines; and

- Number of employees in service (Table 8). This information is derived from the number of employees on the payroll of the mining companies, irrespective of whether they are hospitalised or on holiday, including employees contracted to the mines. This information forms part of the country’s total employment as mining contribution when employment is reported per sector by Statistics South Africa.
The total number of noise exposed employees (Categories A, B and C) in the SAMI increased by 11.75% from 276 042 at the end of 2014 to 308 494 at the end of 2018. The exclusion of Manganese mining from this data, as manganese data were not recorded for 2014 and 2015, results in an increase of 9.86% for the same period.

In comparison the number of employees employed for the same period decreased by 7.4% (Table 8) from 492 931 at the end of 2014 to 456 438 at the end of 2018.

The data would suggest that the percentage of employees exposed to occupational noise in the SAMI is increasing, i.e. although fewer people are being employed (Table 8) a higher number of employees are exposed to noise in the working environment.

Table 7: Number of employees at work (2013 to 2017) as summarised from the Mine Health and Safety Inspectorate reports

<table>
<thead>
<tr>
<th>Commodity</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>111 072</td>
<td>107 795</td>
<td>109 518</td>
<td>106 107</td>
</tr>
<tr>
<td>Chrome</td>
<td>18 400</td>
<td>18 199</td>
<td>15 277</td>
<td>16 947</td>
</tr>
<tr>
<td>Coal</td>
<td>82 082</td>
<td>74 542</td>
<td>69 223</td>
<td>74 255</td>
</tr>
<tr>
<td>Copper</td>
<td>3 154</td>
<td>3 103</td>
<td>3 087</td>
<td>3 102</td>
</tr>
<tr>
<td>Iron-Ore</td>
<td>21 369</td>
<td>20 291</td>
<td>16 146</td>
<td>17 045</td>
</tr>
<tr>
<td>PGM</td>
<td>142 522</td>
<td>167 613</td>
<td>155 524</td>
<td>157 268</td>
</tr>
<tr>
<td>Diamonds</td>
<td>15 701</td>
<td>17 836</td>
<td>19 308</td>
<td>18 640</td>
</tr>
<tr>
<td>Manganese</td>
<td>9 914</td>
<td>8 688</td>
<td>7 234</td>
<td>7 671</td>
</tr>
<tr>
<td>Other Mines</td>
<td>43 510</td>
<td>41 107</td>
<td>38 663</td>
<td>38 893</td>
</tr>
<tr>
<td>TOTAL RSA</td>
<td>447 724</td>
<td>458 174</td>
<td>433 980</td>
<td>439 929</td>
</tr>
</tbody>
</table>

Table 8: Number of employees employed (2013 to 2018) as reported in the Minerals Council South Africa Facts and Figures 2018

<table>
<thead>
<tr>
<th>Commodity</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>119 007</td>
<td>115 029</td>
<td>116 572</td>
<td>112 901</td>
<td>100 189</td>
</tr>
<tr>
<td>Chrome</td>
<td>18 658</td>
<td>18 450</td>
<td>15 449</td>
<td>16 968</td>
<td>18 935</td>
</tr>
<tr>
<td>Coal</td>
<td>86 106</td>
<td>77 747</td>
<td>77 259</td>
<td>82 372</td>
<td>89 647</td>
</tr>
<tr>
<td>Iron-Ore</td>
<td>21 794</td>
<td>20 554</td>
<td>16 651</td>
<td>17 510</td>
<td>18 613</td>
</tr>
<tr>
<td>PGM</td>
<td>186 864</td>
<td>186 465</td>
<td>172 556</td>
<td>172 760</td>
<td>167 041</td>
</tr>
<tr>
<td>Diamonds</td>
<td>15 356</td>
<td>18 313</td>
<td>18 789</td>
<td>18 038</td>
<td>16 361</td>
</tr>
<tr>
<td>Manganese</td>
<td>9 971</td>
<td>8 639</td>
<td>7 242</td>
<td>7 780</td>
<td>9 352</td>
</tr>
<tr>
<td>Industrial minerals</td>
<td>13 031</td>
<td>12 886</td>
<td>13 222</td>
<td>13 029</td>
<td>12 712</td>
</tr>
<tr>
<td>Other minerals</td>
<td>6 330</td>
<td>5 727</td>
<td>5 797</td>
<td>6 219</td>
<td>6 121</td>
</tr>
<tr>
<td>TOTAL RSA</td>
<td>492 931</td>
<td>480 205</td>
<td>458 291</td>
<td>463 901</td>
<td>456 438</td>
</tr>
</tbody>
</table>

Employees are exposed to noise levels above the currently legislated OEL if they are exposed to noise levels within the DMRE exposure category A ($\geq 105$ dB $L_{Aeq,8h}$) or B ($\geq 85 < 105$ dB $L_{Aeq,8h}$).

As was indicated the number of employees exposed to noise per DMRE exposure category and per commodity, from 2014 to 2017, is presented as Figure 6. The same data for specific commodities (i.e. gold mining, coal mining, chrome mining, copper mining, iron-ore mining, platinum mining, diamond mining, manganese mining and other mining) was assessed.

The percentage of occupational noise exposed employees that were exposed to noise levels above the OEL for all commodities increased by 5.1% from 2014 (203 582 employees) to 2018 (213 899 employees).
From the data analysed it is evident that an increase in over-exposure of exposed employees is evident for gold 5.1% (from 52 373 in 2014 to 55 028 at end of 2018, chrome 77.8.0% (from 9 630 in 2014 to 17 120 at end of 2018), coal 53.5% (from 13 648 in 2014 to 20 952 at end of 2018), platinum 5.7% (from 92 630 in 2014 to 97 921 at end of 2018 and diamond 25.8% (from 5 482 in 2014 to 6 894 at end of 2018 and manganese 143% (from 1 028 in 2016 to 2 505 at end of 2018.

Decreases in percentage of over-exposed employees are noted for copper (46.4%), iron-ore (35.2%) and other mining (38.5%) from 2014 to 2018.

It is however evident that health effects associated to the over-exposure of employees to occupational noise can be expected as large numbers of employees (69.3% for 2018) are still being exposed to noise levels higher than the legislated OEL.

13.3 Detailed personal noise exposure measurements from individual mines

Interrogation of the personal noise exposure data submitted to the DMRE in terms of Section 9.2.7 of the MHSA revealed that:

- The total number of noise exposed employees in the SAMI increased by 9.86% when manganese is excluded or 11.75% with manganese included from 2014 to 2018; and
- The number of employed employees decreased by 7.4% for the same period.

These results would suggest that a larger percentage of employed employees is now included in the Hearing Conservation Programs, as stipulated by legislation.

However, this data does not contain indicators that could be analysed to identify the potential for increased exposure due to exposure time.

An employee’s exposure to noise is primarily determined by three factors, namely:

- The power or strength of the noise emitted by the noise sources or sources (Pa or dB);
- The duration (time) that the employee is exposed to the noise source or sources; and
- The efficiency of any control/s implemented to reduce the effect of any of the first two determinants.

A number of individual mines were approached and requested to volunteer their detailed personal noise exposure results for the 2019 monitoring period. A summary of the number of collected personal noise exposure measurements collected (full shift personal monitoring) during 2019 is presented as Table 9.

Table 9: Summary of detailed 2019 personal full shift noise exposure monitoring data from individual project mines.

<table>
<thead>
<tr>
<th>Project Mine Number</th>
<th>Commodity</th>
<th>Mining Type</th>
<th>Number of samples (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine 1</td>
<td>Gold</td>
<td>Slime dam recovery</td>
<td>244</td>
</tr>
<tr>
<td>Mine 2</td>
<td>Coal</td>
<td>Underground Mining</td>
<td>56</td>
</tr>
<tr>
<td>Mine 3</td>
<td>Coal</td>
<td>Colliery (open cast)</td>
<td>32</td>
</tr>
<tr>
<td>Mine 4</td>
<td>Coal</td>
<td>Colliery (open cast)</td>
<td>157</td>
</tr>
<tr>
<td>Mine 5</td>
<td>Coal</td>
<td>Colliery (open cast)</td>
<td>68</td>
</tr>
<tr>
<td>Mine 6</td>
<td>Coal</td>
<td>Colliery (open cast)</td>
<td>74</td>
</tr>
<tr>
<td>Mine 7</td>
<td>Gold</td>
<td>Underground Mining</td>
<td>345</td>
</tr>
<tr>
<td>Mine 8</td>
<td>Platinum</td>
<td>Underground Mining</td>
<td>114</td>
</tr>
<tr>
<td>Project Mine Number</td>
<td>Commodity</td>
<td>Mining Type</td>
<td>Number of samples (n)</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------</td>
<td>--------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Mine 9</td>
<td>Gold</td>
<td>Underground Mining</td>
<td>1 273</td>
</tr>
<tr>
<td>Mine 10</td>
<td>Coal</td>
<td>Underground Mining</td>
<td>243</td>
</tr>
<tr>
<td>Mine 11</td>
<td>Copper</td>
<td>Underground Mining</td>
<td>456</td>
</tr>
<tr>
<td>Mine 12</td>
<td>Chrome</td>
<td>Underground Mining</td>
<td>265</td>
</tr>
<tr>
<td>Mine 13</td>
<td>Manganese</td>
<td>Underground Mining</td>
<td>47</td>
</tr>
<tr>
<td>Mine 14</td>
<td>Iron-ore</td>
<td>Open cast</td>
<td>283</td>
</tr>
<tr>
<td>Mine 15</td>
<td>Diamond</td>
<td>Underground Mining</td>
<td>194</td>
</tr>
<tr>
<td>Mine 16</td>
<td>Diamond</td>
<td>Underground Mining</td>
<td>224</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>4 075</strong></td>
</tr>
</tbody>
</table>

The personal noise exposure levels reported by the project mines confirm the observation made from the DMRE data in that a large number of employees are exposed to noise levels above the OEL of 85 dB$_{LAeq}$. The percentage of over-exposed employees during 2019 range from 18.9% at the project iron-ore mine to 57.3% at the project diamond mines (see Figure 7).

The current OEL for personal exposure to noise assumes that a working shift will not be more than 8 hours per shift and not more than 40 hours per week. It is also safe to assume that the personal noise exposure sampling time will in all cases be less than the actual working shift time. This assumption is made due to the fact that the employee only receives the personal noise dosimeter after arriving at work and will also return the noise dosimeter prior to the end of his/her working shift, prior to departing for home.

Interrogation of the project mines personal noise exposure data revealed that working shifts more than eight hours per day is frequently experienced. The percentage of collected samples that exceeded an eight-hour working shift ranged from 17.7% at the project platinum mine to 100% at the project diamond mine. No sampling time data was received from the project manganese mine.

Working shifts longer than twelve hours were also recorded at the project gold mines (13.9% of collected samples), 1.8% at the project coal mines; 2.7% at the project chrome mine and 2.1% at the project iron-ore mine (see Figure 8).
Figure 7: Summary of percentage personal noise exposure data collected during 2019 by the project mines per exposure category

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Gold</th>
<th>Platinum</th>
<th>Chrome</th>
<th>Manganese</th>
<th>Iron-ore</th>
<th>Diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of personal sampling &gt;105 dB(A)</td>
<td>0</td>
<td>1.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>% of personal sampling ≥85 ≤ 105 dB(A)</td>
<td>30.2</td>
<td>54.5</td>
<td>43.4</td>
<td>56.9</td>
<td>32.0</td>
<td>18.9</td>
<td>57.3</td>
</tr>
<tr>
<td>% of personal sampling &gt;85 dB(A)</td>
<td>30.2</td>
<td>55.7</td>
<td>43.4</td>
<td>56.9</td>
<td>32.0</td>
<td>18.9</td>
<td>57.3</td>
</tr>
</tbody>
</table>

Figure 8: Summary of percentage personal noise exposure data collected during 2019 by the project mines per sampling time category

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Gold</th>
<th>Platinum</th>
<th>Chrome</th>
<th>Manganese</th>
<th>Iron-ore</th>
<th>Diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of personal sampling with duration &gt;12 hours</td>
<td>1.8</td>
<td>13.9</td>
<td>0</td>
<td>2.7</td>
<td>0</td>
<td>2.1</td>
<td>0</td>
</tr>
<tr>
<td>% of personal sampling with duration 8-12 hours</td>
<td>71.8</td>
<td>50.3</td>
<td>17.7</td>
<td>33.7</td>
<td>0</td>
<td>94.7</td>
<td>100</td>
</tr>
<tr>
<td>% of personal sampling with duration &gt;8 hours</td>
<td>73.6</td>
<td>64.2</td>
<td>17.7</td>
<td>36.4</td>
<td>0</td>
<td>96.8</td>
<td>100</td>
</tr>
</tbody>
</table>
13.4 **Equipment Noise Levels Reported by Member Mines to the Minerals Council South Africa**

Strategies to limit occupational noise exposure and eliminating noise-induced hearing loss in the SAMI were discussed at the MHSC summit held during 2003, and it was decided that “by December 2013, the total noise emitted by all equipment installed in any workplace must not exceed a sound pressure level of 110 dB(A) at any location in that mine”.

This milestone was subsequently updated at the MHSC summit in 2014, to state that “by December 2024, the total operational or process noise emitted by any equipment must not exceed a milestone sound pressure level of 107 dB(A). (This milestone of the sound pressure levels will be verified by initiatives under the Centre of Excellence (CoE) and Mine Occupational Safety and Health (MOSH) initiative and reviewed in 2016).

On 4 May 2005, the Chief Inspector of Mines (CIoM) issued an instruction to track the noise milestones (Republic of South Africa. Department of Minerals and Energy, 2005). This instruction included the reason for the instruction, measurement criteria, instrument settings to be used, measurement procedures, recording of results procedure, reporting format and reporting frequency.

The MOSH responded to the September 2014 summit milestone by developing and introducing a “Guidance note for noise measurements of equipment to ensure compliance with MHSC milestones” (Chamber of Mines, 2016). This note elaborated on the CIoM instruction by updating the measurement criteria, instrument settings detail and general procedure. The MOSH guidance note also expanded on the CIoM instruction reporting and recording of results section by introducing a specific procedure for data collection and data reporting.

The MOSH guidance note also introduced the logarithmic average formula to be used for reporting purposes. The formula is indicated as being:

\[
L_{Aeq} = 10 \log_{10} \frac{\log_{10} L_1 + \log_{10} L_2 + \log_{10} L_3 + \log_{10} L_4 + \ldots}{n}
\]

Where:
- \(L_n\) = the noise levels measured (\(L_{Aeq}\)) in dB(A) for each equipment type.
- \(N\) = the number of individual equipment pieces

To facilitate recording and reporting the MOSH established a web-based data capturing tool. Participating mines can register and then enter their information directly into the data base at:

- [https://www.thehealthsource.org/Apps/Index.aspx](https://www.thehealthsource.org/Apps/Index.aspx)
- [https://www.thehealthsource.org/MCSA/MainFrame.aspx](https://www.thehealthsource.org/MCSA/MainFrame.aspx)

The data entered by the mines is then utilised to calculate a Risk Ranking Value for critical noise equipment.
This Risk Ranking is calculated as follows:

- The data for each screened critical noise equipment is recorded in terms of ten risk ranking parameters (RRP). Each risk ranking parameter is assigned a weighing percentage.
- The risk ranking for each of the screened critical noise equipment is then calculated as:
  - Step 1: The individual parameter rating scores for each RRP is multiplied by the RRP weighing % for that RRP.
  - Step 2: The sum (total) of the above results for all RRP is divided by 100.
- The severity of the resulting risk ranking is then classified into 3 categories, namely:
  - Score of 0 to 4 = Green Category;
  - Score of 4 to 7 = Yellow Category; and
  - Score of 7 to 10 = Red Category.

The data and results generated from the MOSH data is at this stage only utilised internally by the Minerals Council South Africa Group Environmental Engineers to identify and prioritise noise control interventions and strategies. The data has not yet been officially published.

To allow programmatic investigations of the data, it was required to compile a classification of equipment. A common classification is used for the vibration and the noise parts of this project. Distinction was made between surface and underground equipment. On surface, distinction was made between trackless equipment, semi-stationary equipment, and stationary equipment. The same trackless class was used for underground, but further consideration was also made for trackbound equipment, hand-held equipment, and stationary equipment. Each of these classes are further subdivided as indicated in Figure 9.
A detailed summary of the MOSH data was performed, where the data for each commodity is presented as summary data in terms of the various:

- Operating areas (i.e. plant, surface and underground);
- Equipment type per operating area (i.e. Handheld, semi-stationary, stationary, trackless, trackbound).
- A list of specific items (noisy equipment) is indicated; and
- The percentage of specific items per exposure category (<82.5, 82.5 to 85, 85 to 104; and >104 dB[A]) is indicated.
An example of the data presentation format is depicted as Figure 10. The MOSH data consist of categorised noise exposure data with the following sample size:

- Coal Mining – 628 sample results.
- Diamond Mining – 170 sample results.
- Gold Mining – 447 sample results.
- Platinum Mining – 429 sample results.
- Other Mining – 154 sample results.

<table>
<thead>
<tr>
<th>Operating Area</th>
<th>Equipment Type</th>
<th>Specific Item</th>
<th>No. of samples (n)</th>
<th>% of equipment in range</th>
<th>&lt; 82.5 dB(A)</th>
<th>82.5 - 85 dB(A)</th>
<th>85 - 104 dB(A)</th>
<th>&gt; 104 dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
<td>Handheld</td>
<td>Blower</td>
<td>3</td>
<td>0</td>
<td>33.3</td>
<td>66.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Descaler</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Needle hammer</td>
<td>1</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hand drill</td>
<td>9</td>
<td>55.6</td>
<td>33.3</td>
<td>11.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grinder</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact tool</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Saw</td>
<td>1</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Semi-Stationary</td>
<td>Cutting torch</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Welding Machine</td>
<td></td>
<td>9</td>
<td>33.3</td>
<td>33.3</td>
<td>33.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Boilermaker equipment set</td>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 10: An example of how the Minerals Council South Africa equipment noise data was presented (Dekker et. al., 2020)

A summary of the Minerals Council South Africa equipment noise data with exposures higher than 104 dB(A) is presented as Figure 11. From this data it is evident that there is still a number of equipment types utilised by the SAMI that produce noise levels above 85dB(A) and some of these still generate noise levels above 104 dB(A).

Figure 11: Summary of the Minerals Council South Africa equipment noise data with exposure >104 dB(A)
The Minerals Council South Africa database does unfortunately not provide any data to enable the identification of potential determinants such as: equipment type, equipment power or capacity, etc.

13.5 Compensation Data Obtained from Rand Mutual Assurance Company Limited (RMA)

NIHL can result from a long latency period after exposure to noise. This can range from immediate (e.g. damage caused by noise and pressure waves from an explosion) to continuous exposure to slightly elevated noise levels over several years.

The number of employed employees varies considerably between commodities and even between various calendar years within the same commodity. It was therefore required to conduct comparisons between commodities by the introduction of a standardized rate. The compensated NIHL rate (number of NIHL cases per 100 000 employees) were calculated by considering the number of approved and compensated NIHL cases during any specific calendar year and the number of employed employees during that same calendar year.

The total number of employed employees in the SAMI decreased by approximately 15.4% from 2008 to 2018 (Figure 12).

The calculated NIHL compensation rate for the same time period (2008 to 2018) decreased by 55.8% (Figure 13).

![Figure 12: Number of employed employees in the SAMI from 2008 to 2018](image-url)
If it can be assumed that all other variables influencing the approval of NIHL claims for compensation being consistent between 2008 and 2018, then it could be concluded that a major improvement in noise exposures has been achieved during this time period. The percentage of employed employees compensated for NIHL reduced from 0.226% to 0.100% for the period 2008 to 2018 (Figure 14).

Figure 13: NIHL Compensation rate for the SAMI from 2008 to 2018

Figure 14: Percentage of employed employees compensated for NIHL from 2008 to 2018
From the commodity specific data it is evident that the calculated NIHL Compensated rates from 2008 to 2018 decreased as indicated in Table 10.

**Table 10: Commodity specific decrease in NIHL Compensated cases per 100 000 employed employees from 2008 to 2018**

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Rate (NIHL Compensated per 100 000 employed employees)</th>
<th>% Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>382, 177</td>
<td>53.7%</td>
</tr>
<tr>
<td>Coal</td>
<td>52, 16</td>
<td>69.2%</td>
</tr>
<tr>
<td>Chrome</td>
<td>171, 63</td>
<td>63.2%</td>
</tr>
<tr>
<td>Diamonds</td>
<td>27, 0</td>
<td>100%</td>
</tr>
<tr>
<td>Other</td>
<td>481, 198</td>
<td>58.8%</td>
</tr>
<tr>
<td>Platinum</td>
<td>114, 97</td>
<td>14.9%</td>
</tr>
<tr>
<td>Manganese</td>
<td>0, 0</td>
<td>0%</td>
</tr>
</tbody>
</table>

It is important to note that although a percentage decrease in NIHL rates is evident for all commodities the rate for platinum and manganese mining indicates an increase trend in the NIHL compensation rate.

The calculated NIHL compensation rate for coal mining increased by 129% from 2012 to 2018. This upward trend seems to be continuing at an alarming rate.

A more thorough breakdown of “Other mines” could not be achieved due to limitations in the source data. It is however concerning that a large portion of compensated NIHL cases originate from this group and that the exact commodity could not be identified.

**13.6 NEW NOISE CONTROL STRATEGIES AND TECHNOLOGIES (SOUTH AFRICA AND INTERNATIONALLY) SINCE 2010.**

The results from a literature study revealed the following most recent noise exposure trends and control initiatives since 2010, both from an international and a national perspective and are summarised as Table 11. It is evident that most research focus is toward coal mining and then also more towards the reduction of noise by means of engineering controls.

**Table 11: Summary of short literature study of most resent noise exposure trends and control initiatives**

<table>
<thead>
<tr>
<th>Source</th>
<th>Relevance</th>
<th>Finding/s</th>
<th>Applicable Commodity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>- Total annual noise dose for surface coal mines decreased by 67%;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Total annual noise dose for underground coal mines decreased by 24%.</td>
<td></td>
</tr>
<tr>
<td>Steenkamp (2018)</td>
<td>Noise measurement</td>
<td>A system of “noise mapping”, by using a sound camera, to identify key sources of noise within a system, processes or equipment.</td>
<td>All Surface</td>
</tr>
<tr>
<td>Saleh, et al. (2017)</td>
<td>Engineering Control</td>
<td>The use of noise damping mats to reduce heavy-equipment noise exposures in construction. The effectiveness and practicality of various sound barriers were evaluated.</td>
<td>All</td>
</tr>
</tbody>
</table>
The Minerals Council South Africa MOSH has developed and introduced the following strategic initiatives to address the reduction of noise exposure to employees:

- Hearing protection device: Training, Awareness and Selection (HPD TAS) Tool;
- Tyre Deflation Leading Practice; and
- Industry-wide Buy and Maintain Quiet Initiative (IBMQI)

The most recent relevant research conducted by the MHSC include:

- A Practical Guide to Noise and Vibration Control in The South African Mining Industry (Van Niekerk, 2005);
- Quantification of Noise Sources in Mechanical Board and Pillar Coal Mining (Heyns, 2001);
- An Examination of Methods Whereby Noise Levels in Current and New Equipment may be Reduced (Maneylaws, 1997);
13.7 Practicality of Implementation

As part of the evaluation, the mines' views on the practicality of implementing the existing OEL for noise were assessed by circulation of a questionnaire to the 16 participating project mines. Thirteen of the mines returned a completed questionnaire, mostly completed by the Mine Occupational Hygienists. A summary of the questionnaire results is shown in Table 12.

Table 12: Summary of the Project Mines View on the Practicality of Implementation of the Existing OEL for Noise

<table>
<thead>
<tr>
<th>Question / Statement</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The current OEL of 85 dB(A) is onerous and must be reduced.</td>
<td>31%</td>
<td>69%</td>
</tr>
<tr>
<td>Employers must be allowed to subtract the protection offered from Hearing Protection Devices from the measured full shift exposure and report this numerical value as the actual exposure value.</td>
<td>46%</td>
<td>54%</td>
</tr>
<tr>
<td>Preventative maintenance of equipment is not done and therefore noise levels from equipment increase over time.</td>
<td>69%</td>
<td>31%</td>
</tr>
<tr>
<td>The employer does not do enough to reduce noise sources from equipment.</td>
<td>15%</td>
<td>85%</td>
</tr>
<tr>
<td>The equipment manufacturers and suppliers do not do enough to reduce noise sources from equipment.</td>
<td>77%</td>
<td>23%</td>
</tr>
<tr>
<td>The employee does not do enough to protect him/herself from exposure to noisy equipment.</td>
<td>69%</td>
<td>31%</td>
</tr>
<tr>
<td>There is currently no new technology that will assist in the reduction of noise from equipment.</td>
<td>31%</td>
<td>69%</td>
</tr>
<tr>
<td>There is currently new technology that will assist in the reduction of noise from equipment, but these are expensive and/or difficult to implement.</td>
<td>69%</td>
<td>31%</td>
</tr>
<tr>
<td>The control of noise is a high management priority at our operation.</td>
<td>77%</td>
<td>23%</td>
</tr>
</tbody>
</table>

The method to amend noise OELs, in the South African context, is described in the noise literature review. Here it is stated as “A new or revised OEL must be practicable and be able to be achieved in the period allocated therefore and the technology and/or knowhow must exist to achieve compliance”.

13.8 Financial Model

13.8.1 Introduction

This chapter provides an overview of the financial model developed for this project, along with the cost determination associated with the current noise exposure. The financial model presented, and the derived financial implication which has been determined based on this financial model, represents an approximation of the true cost associated with the current noise exposure levels. It is noted that while every effort has been made to determine the most
accurate costing implications, assumptions needed to be made based on the availability of information.

The cost determination presented in this study is partly based on that done in by the US OSHA, Department of Labour (Occupational Exposure to Respirable Crystalline Silica, Final rule., 2016). That being, as the financial implications will arise over an extended period of time, these future costs and future benefits will be presented in an annualised format using a present value of future costs technique. The sections that follow represent a summary of the financial model.

13.8.1.1 Cost Determination

The financial costs associated with the current mineworker exposure all arise as a direct result of the NIHL. The model, as a result, has developed a framework which estimates the future financial costs (associated with current mineworker exposure) for each cost category as shown in Table 13.

13.8.1.2 Financial Model NIHL Cost Equation

The cost equation of this particular study and the description of these elements is shown, for reference, in Table 13:

Table 13: Cost Equation

<table>
<thead>
<tr>
<th>COST EQUATION</th>
<th>COST, BENEFIT &amp; DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cp + Cr + Ct + Ci + 0.72 x Cl</td>
<td>COSTS relating to:</td>
</tr>
<tr>
<td></td>
<td>1) NIHL lump-sum pay-outs (Cp);</td>
</tr>
<tr>
<td></td>
<td>2) Replacement workers (Cr);</td>
</tr>
<tr>
<td></td>
<td>3) Training costs (Ct);</td>
</tr>
<tr>
<td></td>
<td>4) Incident investigations (Ci); and</td>
</tr>
<tr>
<td></td>
<td>5) Lost earnings (Cl).</td>
</tr>
</tbody>
</table>

Note: The above computational equations are based on a South African corporate tax rate of 28%. More details on this, along with other assumptions included in the model, is provided in sub-sections that follow.

13.8.2 Methodology

The financial model methodology, along with the various assumptions made, for each of the cost elements highlighted in the cost equation is available upon request.

13.8.3 Results

The result of the financial analysis as described by the methodology indicated a total financial impact of R 74 805 796 (Figure 15).
The biggest contributing factors to the total financial impact was that of electromagnetic pulse (EMP) noise-induced hearing loss lump sum pay-outs, EMP noise-induced hearing loss replacement costs and the indirect cost attributable to a reduced output. When combined, these three cost elements made up 87.1% of the overall financial impact.

### 13.8.3.1 EMP NIHL lump sum pay-outs

Unpacking the cost associated with EMP lump sum pay-outs, which totalled R 47 233 671, the biggest commodities impacted were that of Gold and Platinum which contributed 37.2% and 33.0% to the total overall pay-out respectively. The results also indicated that an average number of 652 mine workers would be impacted annually, translating into the total annual cost as presented.

### 13.8.3.2 EMP NIHL Replacement Mine Workers

As was the case with the EMP NIHL lump sum pay-outs, the biggest commodities impacted were that of Gold and Platinum which made up 40.5% and 31.3% of the total cost estimate of R7 687 889 respectively. Using the claim multiplier, to reflect all those workers which will take sick leave for EMP NIHL reasons, the number of observed cases (for which a mine worker will be on sick leave associated) was calculated to be 818 annually.

### 13.8.3.2.1 Reduction in ‘output’

The reduction in output results in an annualised cost of approximately R 10 257 323. This cost is directly linked to key assumptions relating to the output multiplier, the diagnosis period and the South African corporate tax rate.
14 RELEVANCE AND APPLICABILITY OF CURRENT NOISE OELS

A virtual workshop was held with invited members of the SAMI in order to review the relevance and applicability of current noise OELs. The members from the SAMI comprised of members from organised labour, employers and state.

Participants to the workshop were presented with preliminary results from previous milestones of this project, through the Google Meet platform. The participants were then asked to contribute to the discussion by answering some leading questions, followed by an opportunity to motivate their answers.

A total of 52 participants were involved in the discussion and an average of 79% of these participants engaged with the project team, through the PollEV platform. The participants comprised of:

- 22 participants from consulting companies and service provider companies;
- 3 participants from instrument and equipment supplier companies;
- 14 participants from mining companies;
- 4 participants from industries other than mining;
- 2 participants from the MCSA;
- 2 participants from unions and associations;
- 1 participant from the DMRE; and
- 1 participant from a research agency

The question categories and individual questions are shown in Table 14, and the feedback on the questions are shown in Figure 16 and Figure 17.

Table 14: Categories of questions and Individual Questions asked

<table>
<thead>
<tr>
<th>Category</th>
<th>Question Asked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison of SAMI Noise OEL to International Norms</td>
<td>Q1</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
</tr>
<tr>
<td></td>
<td>Q3</td>
</tr>
<tr>
<td>Legislated Noise Exposure Reporting Methodology</td>
<td>Q4</td>
</tr>
<tr>
<td></td>
<td>Q5</td>
</tr>
<tr>
<td>Methodology to Investigate Personal Noise Exposures Higher than OEL</td>
<td>Q6</td>
</tr>
<tr>
<td>Risk Ranking Methodology to</td>
<td>Q7</td>
</tr>
<tr>
<td>Category</td>
<td>Question Asked</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Prioritize Equipment Noise</td>
<td>Q8</td>
</tr>
<tr>
<td>Reduction Strategies</td>
<td></td>
</tr>
</tbody>
</table>
Q7 | Do you believe that a Risk Ranking Method for equipment noise should be implemented for prioritization purposes?

Q6 | Do you believe that the current noise over-exposure methodology must be enhanced to include the “NIOHS Accumulative % Dose” method?

Q5 | Do you believe that the DMRE Exposure Categories for personal noise exposure should be changed as suggested?

Q4 | Do you believe that the current DMRE Noise Exposure report must be revised to include the reporting of Peak Sound Level?

Q3 | Do you believe that the current personal noise Peak Sound Level of 135 dB(A) must be reduced?

Q2 | Do you believe that the current personal noise exposure OEL must not be revised BUT that more effort must be given to reducing current…

Q1 | Do you believe that the current personal noise exposure OEL of 85 dB(A) must be reduced?

Figure 16: Summary of responses received for Questions 1 - 7

Figure 17: Summary of discussion for answers on Question 8: Do you think that a Risk Ranking Method for equipment noise should be:
15 PROPOSED NOISE OELS AND ASSOCIATED GUIDANCE NOTE

15.1 OCCUPATIONAL EXPOSURE LIMITS FOR NOISE

15.1.1 Rationale

It is argued that a reduction in the legislated noise exposure limit in South Africa will add little value in reducing employees' exposure to high levels of noise. The essence of the argument is however presented here.

Employees are exposed to noise levels above the currently legislated OEL if they are exposed to noise levels within the DMRE exposure category A ($\geq 105 \text{ dB } L_{Aeq,8h}$) or B ($\geq 85 < 105 \text{ dB } L_{Aeq,8h}$).

The percentage of occupational noise exposed employees that were exposed to noise levels above the OEL for all commodities increased by 5.1% from 2014 (203 582 employees) to 2018 (213 899 employees). Based on historic noise exposure data for the SAMI (2014 to 2018) it is expected that the negative health effects associated with the over-exposure of employees to occupational noise can be expected, as large numbers of employees (69.3% for 2018) were still being exposed to noise levels higher than the legislated OEL.

The total number of employed employees in the SAMI decreased by approximately 15.4% from 2008 to 2018. The calculated NIHL compensation rate for the same time period (2008 to 2018) decreased by 55.8%. The percentage of employed employees compensated for NIHL reduced from 0.226% to 0.100% for the period 2008 to 2018.

It is therefore recommended that the legislated noise exposure limit in South Africa not be changed, and that any new initiatives towards the reduction of employees’ noise exposure should be focused towards:

a) Placing emphasis on the high number of employees exposed to noise levels higher than the legislated limit by revising the DMRE exposure categories;

b) Implementation of focused investigation methodology, i.e. “Cumulative Noise Dose”, to identify reasons for high exposures including geographical area, tasks, activities, shift length, etc.;

c) Identifying and prioritizing efforts in reducing noise emitted from specific sources by implementing structured risk assessments and reporting mechanisms.

15.1.2 Proposed Occupational Exposure Limit

The guidance note provides a framework for employers at all mines to implement best international practice regarding the risk of noise exposure in the SAMI. The South African Mining Industry Occupational Exposure Limit for noise is regulated in terms of regulation 22.9(2)(b) of the MHSA. It is regulated as being:

(1) Noise Exposure: $85 \text{ dB } L_{Aeq,8h}$: and

(2) Peak Sound Level: $135 \text{ dB(A)}$.

The $85 \text{ dB } L_{Aeq,8h}$ relates to the maximum noise exposure that an employee might be exposed to for an 8-hour workday and a 40-hour work week. This exposure is obtained from full shift personal exposure monitoring.
Personal Noise Exposure results are currently reported to the DMRE as being within one of three exposure categories, namely:

a) Category A - > 105 dB $L_{Aeq, 8h}$; 

b) Category B - >85 dB $L_{Aeq, 8h}$ to < 105 dB $L_{Aeq, 8h}$; or 

c) Category C - > 82 dB $L_{Aeq, 8h}$ to < 85 dB $L_{Aeq, 8h}$.

**Note:** It is proposed that MHSC revise these exposure categories to be: Category A being >85 dB $L_{Aeq, 8h}$; Category B being > 82 dB $L_{Aeq, 8h}$ to < 85 dB $L_{Aeq, 8h}$ and Category C being < 82 dB $L_{Aeq, 8h}$. This proposal is made due to the fact that both the current Category A (>105 dB $L_{Aeq, 8h}$) and Category B (>85 dB $L_{Aeq, 8h}$) represents noise exposures above the OEL of 85 dB $L_{Aeq, 8h}$. This can be confusing as readers might interpret only Category A exposures as being higher than the OEL.

The SAMI must at all times ensure that during reporting of results, it is made clear that exposures in both the current A and B categories relates to exposures higher than the OEL. Although there is currently no requirement to report the Peak Sound Level to the DMRE, records of the Peak Sound Level for recorded personal noise exposure measurement must be kept for investigation and data analysis purposes until such time as the DMRE revise regulation 9.2(7) and report form 21.9(2)(d) to also allow for the Peak Sound Level to be reported to the DMRE.

**Important Note:** The purpose of the noise exposure categories is to give direction to the personal exposure sampling frequency and the number of samples to be collected.

The DMRE guideline for a COP does not indicate how these exposure categories must be dealt with in the Mines Hearing Conservation Program or Medical Surveillance Program.

Personal exposure to above 105 dB $L_{Aeq, 8h}$ could still be used as an indicator for the need of 6 monthly audiometric testing. Therefore, not all employees in the “A Category” should be subjected to 6 monthly audiometric testing. Only those occupations > 105 dB $L_{Aeq, 8h}$ should be considered for 6 monthly audiometric testing, if so indicated in the mines Hearing Conservation Programme or Medical Surveillance Programme."

The project team proposal to alter the exposure categories will therefore have no influence (no increase in number or cost) on either an increase in personal samples to be collected or the number and type of audiometric tests to be conducted.

**15.1.3 Proposed Guidance Note for the measurement and assessment of Noise in the South African Mining Industry**

A proposed guidance note for the measurement and assessment of noise in the South African mining industry was developed and is attached to this report as Appendix 25.1.
PART 3 | VIBRATION
16 LITERATURE REVIEW – VIBRATION

As part of the investigation, a comprehensive literature survey was conducted. This section presents the main findings and is structured as in Figure 18.

Figure 18: Literature Review - Vibration Overview

16.1 OCCUPATIONAL EXPOSURE TO VIBRATION

Vibration has long been realised as a source of possible harm to the human body. Vibration-induced white finger was first recognised in the limestone quarries of Bedford, Indiana as early as 1890-1900 (Taylor et al., 1984; Taylor, 1988) and was subsequently reported in Italy in 1911 (Griffin, 1990). Since then hammers and chisels used in mining operations have been replaced by pneumatic and hydraulic drills. Technical advances like these led to increased hand-arm vibration injuries all around the globe (Taylor et al., 1984; Taylor, 1988).

This trend was confirmed by various epidemiological studies among mine workers and stoneworkers. Such studies have been conducted in many countries, including the United States of America (Taylor et al., 1984; Wasserman et al., 1991), Canada (Narini et al., 1993, Handford et al., 2017), Britain (Rodgers et al., 1982), Sweden (Hedlund, 1989), Italy (Bovenzi et al., 1988, Bovenzi et al., 1994), Korea (Moon et al., 1982) and Japan (Matsumoto, 1977; Sakakibara et al., 1993).

The importance of hand-arm vibration in the mining industry was amply illustrated by the 26 842 vibration-related compensation claims against the British Coal Board (Heaver et al., 2011). It is also clear from the literature that higher awareness of human vibration and preventive measures are having favourable influences.

A study by Van Niekerk, Heyns, Heyns and Hassall (1998) has shown that vibration levels in South African mines are very high and that certain categories of mining operations had a high adverse health risk associated with vibration exposure. Subsequent work by Phillips, Heyns, and Nelson (2007) confirmed these conclusions. The comprehensive epidemiological study was performed on present and past mine workers to determine the prevalence of vibration-induced disorders in rock drill operators. The high adverse health risk was subsequently confirmed by a study by Nyantumbu et al., (2006).

This study by the National Institute of Occupational Health in Johannesburg was based at one mine and involved 156 people that were exposed to vibration and 140 workers that were not exposed to vibration. The study found that 15% of the workers exposed to vibration showed a prevalence of Hand-Arm Vibration Syndrome (HAVS) over a mean period of 5.6 years, which represented a 10% increase compared with the prevalence of the un-exposed workers. This percentage is however surprisingly low, taking into consideration that the exposures were way beyond the exposure limit of 5 m/s² set by the European Union. Nyantumbu et al. (2007) however proved the prevalence of people suffering from HAVS in South Africa, despite the effect being lower than anticipated. It has been postulated that this might be due to the high

16.2 EXISTING VIBRATION LEGISLATION, STANDARDS AND REGULATORY FRAMEWORKS

16.3 SOURCES OF HUMAN VIBRATION IN THE MINING INDUSTRY

16.4 IMPACTS OF HUMAN VIBRATION

16.5 HUMAN VIBRATION ATTENUATION AND CONTROL
ambient temperatures in South African mines. A large study of Swedish construction workers indicated that there is an increased risk of Vibration-induced White Finger (VWF) in a cold environment among workers exposed to HAV (Burström L, et al., 2010).

Commodities like gold and platinum which form the core of the South African underground mining industry, are mainly found in hard rock deposits. Due to the underground ore deposit geology such as the Bushveld Igneous Complex which includes the narrow-reef Merensky deposit, it is difficult to use mechanization in these mines and therefore increases the risk of HAV. High levels of vibration are not only related to hand-arm exposure.

In a recent study (Mayton et al., 2018) show that high and extreme levels of vibration are also encountered for whole-body vibration on rough haul loads, especially in the fore-aft (X) direction. An Indian study (Chaudhary, et al., 2015) shows that more than 90% of blast hole rock drill operators are exposed to whole-body vibration levels which exceed the ISO whole-body vibration upper limits. An Australian study (Wolfgang and Burgess-Limerick, 2014) shows that haul truck drivers on surface mines are exposed to high levels of vibration, with smaller truck leading to higher levels of vibration.

Human vibration is usually separated into two well-defined categories, whole-body vibration (WBV) and hand-transmitted vibration or HAV. Whole-body vibration occurs when the human body is supported on a vibrating surface such as a seat, floor or bed that is vibrating. Hand-transmitted vibration, by contrast, is a form of local vibration where the hand of a person is in contact with a vibrating piece of equipment and the vibration enters the body at the hand (Griffin, 1990).

16.2 EXISTING VIBRATION LEGISLATION, STANDARDS AND REGULATORY FRAMEWORKS

16.2.1 Introduction

As is the case for OELs, the global legislative landscape for the control of vibration in occupational health environments is also somewhat confused.

In Europe, Directive 2002/44/EC of the European Parliament and the Council, on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) was adopted on 25 June 2002. This directive provides a daily exposure action value as well as a daily exposure limit value, standardised to an 8-hour reference period, for WBV as well as HAV exposure. In the United Kingdom the Control of Vibrations at Work Regulations of 2005 were made under the Health and Safety at Work Act 1974 and now implements the European Council Directive 2002/44/EC.

In the east, Korea has a Noise and Vibration Control Act which is intended to enable all citizens to live in a calm and tranquil environment by preventing any damage due to noise and vibration generated in factories, construction work fields, roads, railroads etc. by properly controlling such vibration (Korea, Act No. 12461, Mar 18 2014). Japan also has a vibration regulation law (http://www.env.go.jp/en/laws/air/vibration/index.html) which is aimed at preserving the living environment and protecting peoples’ health.

Like many countries South Africa also has Environmental Regulations for Workplaces (1987, http://www.acts.online.co.za). These regulations, which are tied to the Occupational Health and Safety Act of 1993, state that where hand-held tools vibrate at a frequency of vibration of less than 1 000 Hz and are used at an actual dry-bulb temperature below 6°C, the employer
shall provide the operator of such tools with lined gloves, and ensure that he wears them. South Africa does however not have OELs related to vibration.

16.2.2 Standards

As indicated previously, two categories of human vibration are typically distinguished (AN21E Application Note Human Vibration Measurement EC Directive 2002/44/EC):

- WBV, acting via the buttocks, the back and the feet of a seated person, the feet of a standing person or the back and the head of a recumbent person. Such vibrations may cause backache or damage to the spinal column.
- HAV which are induced via the hands into the body. They may cause, for example, circulatory disorders, bone, and joint or muscle diseases.

Both these categories of human vibration are described in international standards (Table 15).

Table 15: Standards that are potentially relevant to human vibration in a mining environment

<table>
<thead>
<tr>
<th>Standard</th>
<th>Standard Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 2631</td>
<td>Evaluation of human exposure to whole-body vibration</td>
</tr>
<tr>
<td>ISO 5349</td>
<td>Measurement and evaluation of human exposure to hand-transmitted vibration</td>
</tr>
<tr>
<td>ISO 8041</td>
<td>Human response to vibration. Measuring instrumentation</td>
</tr>
<tr>
<td>ISO 8662</td>
<td>Hand-held portable power tools - Measurement of vibrations at the handle</td>
</tr>
<tr>
<td>ISO 6954</td>
<td>Guidelines for the measurement and analysis of WBV with regard to habitability on passenger and merchant ships</td>
</tr>
<tr>
<td>ISO 10056</td>
<td>Measurement and analysis of WBV to which passengers and crew are exposed in railway vehicles</td>
</tr>
<tr>
<td>ISO 10326</td>
<td>Laboratory method for evaluating vehicle seat vibration Practical advice for measurement and evaluation of human vibration can be found</td>
</tr>
</tbody>
</table>

ISO 2631 and ISO 5349 are the two standards which are by far the most commonly referred to in the mining industry.

It is however enlightening to realise that there are a number of other standards which are also relevant, albeit not so commonly referred to. ISO 8041 refers to the measurement instrumentation which could be single instruments, combinations of instruments or computer-based data acquisitioning and analysis systems. ISO 8662 describes type tests for the measurement of vibration at the handles of specific pieces of hand-held portable equipment.

ISO 6954 would not normally be expected to be of interest in a mining context. However, this could well be relevant in mining operations such as the marine mining operations conducted from De Beers Marine mining vessels. Likewise, ISO 10056 will not normally be relevant to mining activities per se. The underground rail transport system in South Africa is however significant from a haulage perspective, and rail vibration could therefore also be relevant to mining in South Africa.

16.2.3 EU Directive 2002/44/EC

In Europe, Directive 2002/44/EC4, lays down 'action values' and 'limit values' for 8-hour exposures (Table 16). For WBV these values are based on the highest weighted root mean square (r.m.s.) acceleration along any of three orthogonal axes as determined according to the ISO 2631 series of standards. For HAV, a vibration total value equal to the vector sum of the weighted r.m.s. accelerations along three orthogonal axes is to be determined according
to the ISO 5349 standards. The Directive lays down minimum requirements and EU member states may adopt more stringent provisions for the protection of workers.

**Table 16: EU Action and Limit Values for Vibration**

<table>
<thead>
<tr>
<th>Whole-body</th>
<th>Hand-arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpretation: VDV results</td>
<td>Interpretation: A(8) results</td>
</tr>
<tr>
<td>≤ 8.5 m/s(^{1.75}) Unlikely health effects</td>
<td>≤ 0.5 m/s(^2) Acceptable</td>
</tr>
<tr>
<td>&gt;8.5 ≤ 17 m/s(^{1.75}) Caution: Health risks are indicated</td>
<td>&gt; 0.5 ≤ 1.15 m/s(^2) Action value</td>
</tr>
<tr>
<td>&gt; 17 m/s(^{1.75}) Health risks are likely</td>
<td>&gt; 1.15 m/s(^2) Exceed exposure limit value</td>
</tr>
</tbody>
</table>

A "health caution guidance zone" for daily WBV exposures is presented in **Table 17**.

**Table 17: Health Caution Guidance Zone for WBV in X, Y, or Z Directions**

<table>
<thead>
<tr>
<th>Daily Exposure Duration (hours)</th>
<th>WBV (Acceleration m/s(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Clear Effects</td>
</tr>
<tr>
<td>4</td>
<td>Less than 0.6</td>
</tr>
<tr>
<td>8</td>
<td>Less than 0.5</td>
</tr>
</tbody>
</table>

### 16.2.4 American Conference of Governmental Hygienists (ACGIH)

The ACGIH TLVs® for HAV ([www.worksafebe.com](http://www.worksafebe.com)) are provided in **Table 18** and refer to component acceleration levels and durations of exposure that represent conditions under which it is believed that nearly all workers may be exposed repeatedly without progressing beyond Stage 1 of the Stockholm Workshop Classification System for VWF.

**Table 18: ACGIH TLVs® for HAV in either Xh, Yh or Zh Directions**

<table>
<thead>
<tr>
<th>Total Daily Exposure Duration</th>
<th>Values of the dominant frequency-weighted r.m.s. component acceleration which shall not be exceeded (m/s(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 hours and less than 8</td>
<td>4</td>
</tr>
<tr>
<td>2 hours and less than 4</td>
<td>6</td>
</tr>
<tr>
<td>1 hour and less than 2</td>
<td>8</td>
</tr>
<tr>
<td>Less than 1 hour</td>
<td>12</td>
</tr>
</tbody>
</table>

Time refers to the total time vibration enters the hand per day, whether continuous or intermittently. It is assumed that one axis of vibration is dominant over the remaining two axes. If one (or more) vibration axis exceeds the total daily exposure, then the TLV® has been exceeded.

### 16.3 Sources of Human Vibration in the Mining Industry

A number of investigations pertaining to human vibration in mining have been conducted in South Africa. This section discusses the most important of these studies and briefly review specific contributions made by these studies. Most of the South African studies focus on the engineering aspects of the human vibration problem and provide comprehensive details about typical vibration exposure levels. In some cases, the daily duration of vibration exposure is also highlighted. Amongst the South African studies only one deals with the epidemiological impacts of the vibration. This study pertains specifically to rock drill vibration.
16.3.1 South African studies

16.3.1.1 COMRO study 1987

The earliest South African reference to human vibration in the mining industry that was found in the present investigation, is a Chamber of Mines Research Organisation (COMRO) Research Report by Franz et al. (1987). Although no findings were reported on the existence of vibration-induced disorders in the South African mining industry, the authors did recommend that a study be undertaken to establish the status of vibration-induced trauma in South Africa. Different tests for the objective evaluation of vibration-induced injury were however reviewed and found lacking in their ability to differentiate consistently between the different stages of impairment. This probably contributed to the fact that this recommendation was never implemented.

16.3.1.2 SIMRAC GEN 503 Study 1998

A decade later a very comprehensive vibration measurement study was conducted by Van Niekerk, Heyns, Heyns and Hassall as part of Project GEN 503 (1998) for the Safety in Mines Advisory Committee (SIMRAC). The objectives of this study were to:

- Quantify vibration levels over a range of equipment.
- Obtain a reliable set of data that could be used to assess exposure levels at the time of investigation.
- Establish actual times that workers could be safely exposed to vibration.
- Identify equipment with hazardous levels of vibration.
- Get an indication of the likelihood that vibration related disorders might be present among workers.

Comprehensive measurements were conducted over a range of equipment causing whole-body vibration as well as hand-arm vibration. Four key parameters were computed to assess the severity of vibration, namely $a_{rms}$, $a_w$, $C_f$ and $VDV_4$. During this study 24 types of equipment were surveyed with measurements on 70 different machines, resulting in more than 700 different sets of data.

From this study it was concluded that the levels of vibration observed during hand-arm vibration measurements were sufficiently high to cause an enhanced level of risk of vibration-induced disorders, in a significant proportion of operators. The most notable examples are hand-held rock drills, pneumatic and hydraulic pavement breakers, jackhammers, and some selected workshop tools.

Because very few operators have been diagnosed with vascular disorders associated with vibration, it raised the question of the importance of temperature as an important determining factor in HAV in South Africa.

It was however also observed during this study that some operators were not holding tight onto the equipment for the entire duration of the equipment being operated. It was also clear from this study that more detailed information about actual exposure times might be needed.

A major recommendation following from this study was that a comprehensive epidemiological study be conducted on past and present workers to determine the prevalence of vibration-induced disorders amongst operators.
16.3.1.3 NIOH Study

In response to the above recommendation the National Institute for Occupational Health (NIOH) continued with the proposed epidemiological study (Nyantumbu et al., 2007). Participants were randomly selected from a list of mine workers from a single gold mine in South Africa. 311 mineworkers were randomly selected to participate in the study and 296 finally participated. The participants were all black males from South Africa and surrounding countries. 156 workers were assigned to the exposed group with current or past occupational history. The control group comprised 140 workers who have not had any history of vibration exposure at all. The majority of exposed workers reported having used rock drills (84%), a smaller group using pick machines (8%) and the remainder using grinders, impact wrenches or small drills.

Among the exposed group the prevalence rate was 15%, while in the non-exposed group 5% had signs and symptoms indistinguishable from hand HAVS. The study therefore demonstrated that vibration-exposed mine workers were three times more likely to report symptoms compatible with HAVS.

It was suggested that the low prevalence of vascular symptoms may in part reflect the high ambient temperature (mean wet bulb temperature of 28.6 °C). Workers also do not report blanching in studies in other warm countries such as India, Singapore, and Vietnam. It was also observed that the prevalence of vascular symptoms under railroad workers in China, depend on geographical location, with a higher prevalence in the colder north.

16.3.1.4 Baseline Vibration Survey at Optimum Coal Mine

While the above-mentioned studies focused on underground mining, Aye and Heyns (2011) conducted a very extensive vibration investigation at the Optimum Open Cast Mine. The study quantified the vibration levels on a range of machinery at Optimum Colliery. An interesting feature of this study is the fact that not only was the ISO 2631-1 standard used to calculate the weighted rms acceleration but the crest factor and the VDVs for whole-body vibration were determined. The more recent ISO 2631-5 was also applied in a follow-up study which used the same data acquired for the Optimum Colliery investigation to explore the impact of shock exposure (Aye, 2009). For this approach, the daily equivalent static compressive dose $S_{ed}$ is also calculated. For HAV the ISO 5349-1 was used to calculate the RMS, A(8) and vibration dose $D_v$. Half of the equipment had vibration levels below the exposure action value (EAV), while the remaining half had levels between the exposure action value and the exposure limit value (ELV). This study represents a very comprehensive study of vibration in open cast mining.

16.3.1.5 Anglo Technical Services

Mdlazi (2008) conducted research to investigate the impact of whole-body vibration on the day to day activities at Anglo American operations in South Africa. It was concluded that there is enough evidence that a number of vehicles and equipment at Anglo operations expose a large number of employees to high vibration levels and that vibration exposure levels have to be managed to minimize the risk of injury. The report proposed that Anglo American should establish an Anglo American database for WBV exposure levels, to facilitate decision making during vibration risk assessment, mitigation of WBV risk and mobile equipment procurement.
16.3.1.6 Mafube Colliery

A very interesting study was conducted at Mafube Colliery. During 2012 (Oberholster et al., 2012) a fairly comprehensive WBV study was performed at Mafube Colliery. It was found that several vehicles exhibited vibration responses that were severe enough to classify the vehicles as uncomfortable according to the ISO 2631-1 standard. It was however also established that the vehicles exposed operators to shock loading, which is more representatively evaluated according to ISO 2631-5. A follow-up study was hence conducted (Kroch and Heyns, 2014) to evaluate the vibration exposures according to this standard. This standard focuses more on human health as opposed to comfort.

16.3.2 International studies

A large number of WBV studies have been conducted internationally. While some of these studies may not be directly relevant to South African conditions, they are reported here because of the possibility of using these studies as benchmarks against which South African study results will be compared. Several questions in the current study relate to specific issues that are relevant in the comparison of South African and international conditions. These include the temperature differences, as well as issues such as road conditions, local skill levels, etc. In a particularly useful study Duarte et al. (2018) review a number of important international WBV studies published between 1990 and 2017. Only experimental studies conducted specifically in the mining industry were considered. Ten studies were reviewed in detail. Duarte et al., (2018) however missed a number of earlier studies conducted by the Silsoe Research Institute for the Health and Safety Executive in the United Kingdom in 2005. Research Report 400 (Scarlett and Stayner, 2005) is a broad report that consider a range of equipment that is generally found in the British industry, and includes WBV on construction, mining, and quarrying machines. This report is valuable because of the extensive detail in which the results are presented. The report is however limited to the engineering information and does not address the effects of the vibration on the human operator.

16.4 Impacts of Human Vibration

16.4.1 Occupational Hygiene and Medical Impacts of Human Vibration

The impact of vibration on the human body is generally very difficult to determine because of the sensitivities involved in exposing humans to harmful vibration levels, but also because of very significant differences between individuals. In the literature there is also very often not very clear distinctions between perception, comfort and bodily harm.

Adverse health effects due to excessive vibration is a slow process. It usually starts just as experiencing pain. If or when exposure continues, the pain may change into an injury or disease or syndrome. Pain is however the first health condition that is noticed. This should be addressed as soon as possible to prevent irreversible injury or disease.

16.4.2 Whole-body Vibration

Workers exposed to WBV, where the whole body is in contact with a vibrating object on a daily basis, may develop vibration associated adverse health effects. WBV is of particular relevance for drivers and operators of transport equipment, machine operators and for humans in buildings, where plants are housed. Workers prone to develop these health effects are operators driving busses, trucks or heavy machinery. Operators working on structures as a
result of equipment that vibrates the work floor may also be influenced if they have to stand still or sit for prolonged periods observing the process. Such workers are however more likely to experience discomfort and even report reduction in performance as a result of the vibration they are exposed to.

The discomfort caused by WBV depends on the vibration magnitude, the vibration frequency, the direction of the vibration, the position at which the vibration contacts the body and the duration of the vibration. It also depends on the posture and orientation of the body and varies significantly between individuals. The transmission of vibration to a seated person can further be greatly affected by the seat (Griffin, 1990).

Human activities very often rely on the transfer of information through the sensory systems of the body and the subsequent processing of this information. Vibration might disturb the normal function of any component of this input/output system. Most often it appears to affect the principal input (eyes) and the principal output (hands).

Possible adverse health effects, discomfort and negative perception usually appears in the frequency range 0.5 Hz to 80 Hz. However, a person is most sensitive to vibration between 0.5 Hz and 20 Hz because the body absorbs the largest amount of vibration energy in this spectrum. The human body can be regarded as a complex system of springs, dampers and weights that reverberate under the influence of vibration, with the maximum amplification between 5 Hz and 11 Hz. As a result, the spinal load increases and the spinal column and more specific the intervertebral discs may be influenced. Degeneration of intervertebral discs and associated lower back pain (Bovenzi et al, 2017), as a result of inflammation, are associated with long-term WBV exposure. Scientific evidence showed however that occupational exposure and smoking (environmental factors) may contribute only 25% to intervertebral disc degeneration. A recent review showed that genetic factors may increase individual susceptibility to develop intervertebral degeneration up to 75%. This genetic predisposition may have a significant impact on selection of workers who may be exposed to whole-body vibration.

When workers are exposed to WBV on a daily basis, the vibration normally results in an overall ill feeling and decreased work performance that is termed “vibration sickness”. Griffin (1990) also reports that the human response to WBV may be considered as involving the following effects; discomfort, interference with activities and impairment of task performance, impaired health, perception of low-magnitude vibration and the occurrence of motion sickness. This is specifically applicable when people or employees travel in sea- and land vehicles. Motion sickness appears at specific frequencies, within the frequency range of 0.1 Hz to 0.5 Hz. Motion sickness syndrome is characterised by pallor, sweating, nausea and vomiting. This is however not commonly experienced in the mining industry (note however the important exception of shipborne mining activities as is found in diamond mining).

The effects of WBV are associated with the frequency range employees are exposed to, however, the most prevalent effect would be associated with the dominant frequency an employee is exposed to. Very low frequencies, around 2 Hz, cause respiratory problems. Heart rate increases when an employee is exposed to vibration. However, with continued exposure the heart rate may return to normal. Blood pressure rises at low frequencies around 5 Hz but drops when the frequency is within the 10 Hz to 20 Hz spectrum. Chest pains, spontaneous muscle contraction, stomach-ache and a general feeling of discomfort occur at frequencies between 5 Hz and 10 Hz. The most important example of physiological effects on the human body is the deterioration in clarity of sight, which is evident at frequencies between
10 Hz and 30 Hz. Frequencies ranging between 14 Hz and 20 Hz have an influence on muscle tone and speech. This frequency spectrum also causes a need to urinate or pass stool.

Shortly after or during exposure the psychological symptoms associated with WBV vary significantly from fatigue, insomnia, headache and dizziness and ‘shakiness’. Studies have shown that workers exposed to WBV were subject to physiological disorders such as circulatory, cardiovascular disease (Hering, Lachowska and Schlaich, 2015), bowel, respiratory, various neuropathies (Stoyneva, 2016), muscular, neck and back pain as well as back and neck disorders. Other factors that are possible causes for these disorders are body posture, postural fatigue and dietary habits. Physiological symptoms associated with WBV exposure over long durations of time are increased heart rate, increased oxygen uptake, as well as increased respiratory rate, and changes in blood and urine.

Various health disorders have been reported among groups of people occupationally exposed to severe WBV. These include back problems, gastrointestinal, reproductive system, visual and vestibular disorders. There is also evidence of inter-vertebral disc injuries and degeneration of spinal vertebrae (Griffin, 1990). A review by Wikström et al. (1994) that was particularly focused on drivers is also believed to be relevant to the present investigation and corroborates these findings.

There is also growing evidence in the scientific literature that whole-body vibration may influence the digestive system (Bovenzi, 2012), genital or urinary and the female reproductive organs.

As discussed, several international standards are available to lay down measurement, evaluation and assessment methods. However, WBV studies still do not provide an acceptable basis for conclusions about the exposure-response relationship between vibration level and the risk of injuries or disorders (Wikström et al., 1994).

ISO 2631-1 deals primarily with comfort. ISO 2631-5 deals with adverse effects on the lumbar spine which are dominating the health risks of long-term exposure to vibration containing multiple shocks. The assessment method is based on the predicted response of the bony vertebral endplate (hard tissue) in an individual that is in good physical condition with no evidence of spinal pathology. It is also assumed that the individual maintains an upright unsupported posture.

16.4.3 Hand-transmitted Vibration

The principal sources of hand-transmitted vibration are tools where the hand and fingers grasp or push vibrating objects (Griffin, 1990). An obvious example from the mining industry is the rock-drill, but a variety of other hand-held and hand-controlled equipment is also responsible for transmitting high levels of vibration to the operator.

Exposure to hand-transmitted vibration is difficult to quantify. Not only does the magnitude of the vibration vary with operating conditions, but also the size, strength and manner of grip of the operators introduce more variables into the measurements. Furthermore, the orientation of the hands, to which the accelerometer is fixed, is not static and may vary during an activity. Studies have shown that the relationships between vibration exposure and disorders are complex, and setting responsible limits is difficult. Many factors affect dose-effect relationships (Brammer, 1986), some of which – such as temperature – have not been studied extensively. Nevertheless, it is known from epidemiological studies that hand-arm vibration may lead to vascular and neurological disorders that may seriously affect the quality of life of the afflicted
person. The rate of development of the disease is described by the latency period, which is the time between the start of exposure and the presentation of symptoms.

Hand-arm vibration exposure affects the blood flow (vascular effect) and causes loss of touch sensation (neurological effect) in fingers. The resulting reduced blood flow to the fingers can also result in white fingers when the hands are exposed to excessively cold conditions. A wide range of disorders could occur as a result of hand-transmitted vibration exposure. Griffin (1990) distinguishes the following types of disorders: vascular disorders, bone and joint disorders, neurological disorders and muscle disorders.

Vascular disorders include impeded blood circulation to the fingers and 'attacks' of blanching on one or more digits. Loss of sensitivity and reduced finger temperature during an attack give some difficulties with fine tasks and manual dexterity. Occasionally necrosis and rarely, gangrene have also been reported (Griffin, 1990).

Bone and joint injuries are mostly associated with percussive pneumatic tools, where it is believed that the repetition frequency around 30 Hz or the high magnitude of the shocks may be the main cause of injury. Generally, there is a very diverse range of signs and symptoms that leave a confused picture of the type and mechanisms of bone and joint injuries (Griffin, 1990; Gemne and Saraste, 1987).

Neurological disorders lead to numbness and reduced tactile sensitivity that are not necessarily restricted to areas affected by blanching. An increased incidence of carpal tunnel syndrome has also been suggested in some users of vibrating tools (Griffin, 1990). There is some difficulty in distinguishing between muscular and neurological disorders, since both their occurrence and the means by which they may be observed can be interdependent. Muscle atrophy has occasionally been reported. More common is reduced dexterity or grip strength (Griffin, 1990).

In the literature, cumulative trauma disorders (CTD) are defined as the accumulation of small, often unnoticeable injuries, which happen over a period of time. These injuries happen by repetitive and sometimes stressful activities, which gradually damage nerves and tissue. These are often viewed as normal aches and pains until permanent damage has occurred (Killough and Crumpton, 1996). In most cases these effects are still considered as normal aches and pains even after permanent damage has occurred. This means that those affected by the condition often do not complain or bring the problem to the attention of others, until they have progressed way beyond the point at which they could have been reported or detected by objective means (Griffin, 1998).

The upper extremities of the body are particularly susceptible to cumulative trauma injuries, because of the almost constant motion of the upper body. Some of these hand-arm related CTDs, which are believed to be of relevance in industry, are briefly reviewed:

16.4.3.1 HAV Syndrome

Hand-arm vibration can cause a variety of health conditions collectively known as HAVS and prolonged exposure to occupational vibration is associated with an increased risk of HAVS (http://www.cdc.gov/niosh). This disorder, which is also known as vibration-induced white finger, dead hand, dead man's hand, dead finger or Raynaud's syndrome, refers to a complex of effects upon the vascular, neurological and musculoskeletal systems. The vascular and neurological symptoms often present together and at similar levels of severity – there may also be negative effects to other body functions, in particular hearing (Greenslade and
Larsson, 1997:144). It has however been shown (Brammer et al., 1987) that the vascular signs and neurological symptoms associated with exposure of the hand to vibration, may develop independently.

It is believed that this possibility for independent development of symptoms may be relevant in the South African context, where it has been speculated that the development of the vascular signs in gold and platinum mine workers might be delayed because of high temperatures in the stopes. An old study on 30 Singaporean dockyard riveters and caulkers (Lloyd Davies et al., 1957) seems to confirm the observation that the prevalence of HAVS tend to reduce in hot climates. This study is however not very conclusive.

When continuously exposed, the development of HAVS steadily increases and so does the severity thereof. HAVS is a chronic, progressive disorder with a latency period that can vary from a few months to many years. The early stages are usually reversible if further exposure to vibration is reduced or eliminated (Greenslade and Larsson, 1997). For advanced stages, treatment is usually ineffective and the disorder can progress to loss of effective hand function and necrosis of the fingers (http://www.cdc.gov/niosh).

Workers affected by HAVS commonly report the following:

- Attacks of whitening (blanching) of one or more fingers when exposed to cold.
- Tingling and loss of sensation in the fingers.
- Loss of light touch.
- Pain and cold sensations between periodic white finger attacks.
- Loss of grip strength.
- Bone cysts in fingers and wrists.

VWF is caused by vibration in the workplace but its acceptance as an industrial disease is complicated by the fact that during the first and routine exposures to vibration the disease pain is not apparent, the disease does not prevent the worker from doing his job for a long time and the causes of VWF cannot always be identified.

The VWF symptoms may occur months or years after the start of the exposure, depending on the intensity of such exposure. Two important features of the relationship between vibration exposure and health effects are the threshold value or tolerable vibration and its latency period. The latter depends on the first occupational exposure to hand-arm vibration and the intensity of the exposure. The higher the intensity of the hand-arm vibration, the shorter the latency period. The latency periods of some occupations are reflected in Table 19.

Table 19: Latency periods for selected occupations (Brammer et al, 1982)

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Stage of VWF</th>
<th>Latency (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundry worker</td>
<td>Tingling</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>Numbness</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Blanching</td>
<td>2.0</td>
</tr>
<tr>
<td>Shipyard worker</td>
<td>Tingling</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>Numbness</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>Blanching</td>
<td>16.8</td>
</tr>
<tr>
<td>Chain saw operator</td>
<td>Numbness</td>
<td>4.0</td>
</tr>
<tr>
<td>Grinder</td>
<td>Blanching</td>
<td>13.7</td>
</tr>
</tbody>
</table>
Occupational health physicians and other medical personnel have composed a classification system for the vascular differences in the hand-arm as a result of vibration exposure as reflected in Table 20 and Table 21 for vascular- and sensorineural symptoms, respectively.

**Table 20: Stockholm Workshop Classification Scale for cold-induced peripheral vascular symptoms (Gemne et al., 1987)**

<table>
<thead>
<tr>
<th>Vascular assessment Stage</th>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
<td>No attacks</td>
</tr>
<tr>
<td>1</td>
<td>Mild</td>
<td>Occasional attacks affecting only the tips of one or more fingers</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>Occasional attacks affecting fingertips and middle of the finger (distal and middle phalanges), and also rarely affects the parts of the finger close to the palm (proximal phalanges)</td>
</tr>
<tr>
<td>3</td>
<td>Severe</td>
<td>Frequent attacks affecting all parts of most fingers (all phalanges)</td>
</tr>
<tr>
<td>4</td>
<td>Very Severe</td>
<td>Same symptoms as in stage 3 with skin changes in the fingertips.</td>
</tr>
</tbody>
</table>

**Table 21: Stockholm Workshop Classification Scale for cold-induced peripheral sensorineural symptoms (Gemne et al., 1987)**

<table>
<thead>
<tr>
<th>Sensorineural assessment Stage</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSN</td>
<td>Exposed to vibration but no symptoms</td>
</tr>
<tr>
<td>1SN</td>
<td>Intermittent numbness, with or without tingling</td>
</tr>
<tr>
<td>2SN</td>
<td>Intermittent or persistent numbness, reduced sensory perception</td>
</tr>
<tr>
<td>3SN</td>
<td>Intermittent or persistent numbness, reduced tactile discrimination and/or manipulative dexterity</td>
</tr>
<tr>
<td>OSN</td>
<td>Exposed to vibration but no symptoms</td>
</tr>
</tbody>
</table>

This classification can be made for each separate hand of the worker and for the number of fingers of the hand that is being examined. Notation that is used to indicate that the condition of the left hand is stage 4 in three fingers and on the right hand stage 3 in one finger, is denoted as follows: 4L(3)/3R(1).

Sensory-neural assessment is also completed for workers who may be suffering from hand-arm vibration health effects. Occupational Medicine Practitioners use the terminology shown in Table 22 to determine the extent of the damage.

**Table 22: Terminology for determining the extent of hand damage**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSN</td>
<td>Exposed to vibration but no symptoms</td>
</tr>
<tr>
<td>1SN</td>
<td>Intermittent numbness, with or without tingling</td>
</tr>
<tr>
<td>2SN</td>
<td>Intermittent or persistent numbness that reduces sensory perception</td>
</tr>
<tr>
<td>3SN</td>
<td>Intermittent or persistent numbness that reduces tactile discrimination and/or manipulative dexterity</td>
</tr>
</tbody>
</table>

From the above table, the stages in which VWF occurs can be further explained as follows:

- **Stage 1:** In the early stages of vibration exposure, workers may find slight numbness and tingling in the fingers. These symptoms do not interfere with daily work routines.

- **Stage 2:** In this stage the worker is exposed to intense vibration and the fingers may become swollen, inflexible and painful. If the exposure continues, people working in the cold are susceptible to early morning attacks of VWF that can last 15 to 60 minutes. Physical changes in the fingers are more prominent, such as the whitening of those affected.

- **Stage 3:** The worker at this stage has had the typical attacks in the hands/arm, which could occur regardless of season. The worker cannot do fine work and will be unable
to determine if something is hot or cold. Personal recreational activities (i.e. sport) will also be affected.

- **Stage 4**: In chronic and advanced cases of hand-arm exposure, the skin may appear bluish in colour and fingers may lose their ability to open and close quickly. In a minority of cases the worker suffers from the degeneration of the skin at the fingertips.

The severity of hand-arm vibration syndrome depends on several other factors, such as the characteristics of vibration exposure, work practice, personal history and habits. Table 23 summarizes these factors.

**Table 23: Factors that may influence the effect of vibration on the hand**

<table>
<thead>
<tr>
<th>Physical Factors</th>
<th>Biodynamic Factors</th>
<th>Individual Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration of vibration</td>
<td>Grip forces - how hard the worker grasps the vibrating equipment</td>
<td>Operator's control of tool</td>
</tr>
<tr>
<td>Frequency of vibration</td>
<td>Surface area, location, and mass of parts of the hand in contact with the source of vibration</td>
<td>Ability to change or vary the work rate of the machine</td>
</tr>
<tr>
<td>Duration of exposure each workday</td>
<td>Hardness of the material being contacted by the hand-held tools, for example metal in grinding and chipping</td>
<td>Skill and productivity</td>
</tr>
<tr>
<td>Years of employment involving vibration exposure</td>
<td>Position of the hand and arm relative to the body</td>
<td>Individual susceptibility to vibration</td>
</tr>
<tr>
<td>State of tool maintenance</td>
<td>Texture of handle-soft and compliant versus rigid material</td>
<td>Smoking and use of drugs.</td>
</tr>
<tr>
<td>Protective practices and equipment including gloves, boots, work-rest periods</td>
<td>Medical history of injury to fingers and hands, particularly frostbite</td>
<td>Exposure to other physical and chemical agents</td>
</tr>
</tbody>
</table>

It is important to take note of the fact that Raynaud's syndrome is also caused by other factors besides vibration. Other diseases such as connective tissue disease, trauma, disease of the blood vessels, exposure to vinyl chloride and certain medications may also cause such symptomology. This fact must be carefully accounted for in all studies related to the prevalence of vibration disease.

**16.4.3.2 Carpal Tunnel Syndrome**

Carpal tunnel syndrome (CTS) is a specific disease or syndrome caused by hand-arm vibration. The median nerve which transmits sensation to the thumb, index, middle and one-half of the ring finger, and the tendons of the fingers pass through a small opening in the wrist known as the carpal tunnel. If any of the tendons in the carpal tunnel are inflamed or swollen, the median nerve can be pinched, causing pain. Also, the median nerve can be pinched if the fingers are in use, causing the tendons to increase in size, while the wrist is bent. Symptoms of CTS include pain, numbness, and/or tingling of the injured hand. Pain is often most acute at night while sleeping (Killough and Crumpton, 1996:400). Prevention methods include using tools in such a manner that the wrist is not bent while performing the operation, the using of tools with comfortable non-slip handles and taking a break every half-hour from repetitive tasks (Killough and Crumpton, 1996:400).

It may be difficult to distinguish HAVS from CTS, both of which also occur in unexposed populations. A probable cause-effect relationship with CTS has been observed when there is exposure to occupational vibration together with the typically associated repetitive wrist movements (Greenslade and Larsson, 1997:144).
16.4.3.3 HAVS in the United Kingdom

HAVS is the most common compensated occupation related disorder in the United Kingdom (Heaver et al., 2011). Between 2008 and 2009, 850 cases were assessed for industrial injury disability benefit. Year on year this number is however now decreasing because of increased awareness of employers and employees. The improvement in health surveillance ensure that signs and symptoms are recognised earlier and simple measures such as wearing anti-vibration gloves and avoiding unnecessary exposure in conjunction with better designed tools have contributed to the reduced prevalence. The current reduction in the number of new claims can be seen in Figure 19.

Figure 19: Reduction in the number of new HAVS claims in the UK

16.4.3.4 Mechanisation

Although mechanised drill and blast is likely to change the mining landscape in South Africa, some high vibration exposure tasks will remain inevitable for the foreseeable future, due to the difficulty of mechanising operations in South African mines and the slow rate of investment in our mining industry. Work that requires the operator to manoeuvre and guide machinery by hand and body strength usually result in some vibration to the human body and will continue for some years into the future.

16.4.3.5 Exposure Times

It is clear from the literature reviewed that the duration of occupational vibration exposure is generally not very well known. In surface mining activities where operators often drive mining vehicles, these durations are generally better understood. In cases where production capacity is linked to the operation of these vehicles, one can expect these operating periods to be better observed and logged. Some vehicles are however exposed to highly variable loading and associated shocks. Under these circumstances there is more variability to the duration times. Local studies like the SIMRAC, Optimum Colliery and the Mafube Colliery investigations did make some attempt to record exposure duration using interviews (questionnaires) in conjunction with the measurements.

For HAV measurements underground, there is much more uncertainty about the approximate exposure times, as it varies considerably and on a daily basis.
16.5 **Human Vibration Attenuation and Control**

This section explores the use of technological solutions to attenuate human vibration in the mining industry. Many of these solutions may not have been developed far enough for practical implementation, but still represent possible future avenues for research and investigation. While it is probably true that these solutions might not immediately affect occupational exposure levels in South Africa, a thorough understanding of possible solutions is important in taking a longer-term view on occupational health exposure levels in South Africa.

### 16.5.1 Whole-body Vibration Attenuation

McPhee, Forster and Long (2001) from the Australian Joint Coal Board Health and Safety Trust explore the causes of WBV and potential solutions to whole-body vibration problems in the coal mining industry. This category of vibration exposure is very common in the coal mining industry for drivers, operators of mining equipment and passengers.

McPhee et al. (2001) indicate the immediate effects of WBV is often no more than discomfort or fatigue. However, rough rides which cause jolting and jarring while vehicles are in motion are believed to be prime contributors to back and neck disorders in mining. It is believed that there are three main sources of harmful vibration in mining equipment. These are:

- Road roughness and poor work surface conditions;
- Vehicle activity (e.g. ripping, tramming, etc.); and,
- Engine vibration (to a lesser extent).

From this is clear that there are a number of potentially impactful approaches to deal with whole-body vibration in mining environments. The interpretation of the results should guide the professional in deciding where to focus as a non-compliance in terms of the x, y and z-axis of whole-body vibration and provide information with respect to the suspension (y-axis) of vehicles, road surface (z-axis) and driving skills (z- and x-axis), of the vehicles.

#### 16.5.1.1 Road Condition Management

Thompson, Visser, Miller and Lowe (2003) discuss the importance of haul road maintenance management systems in the mining context and indicate that the task often simply becomes so onerous that sub-optimal road maintenance results. In this context they suggest real-time road maintenance management using vibration signatures. This idea is explored further by Ngwangwa et al., (2009) by combining on-board vibration sensors with artificial neural networks, and by Heyns et al., (2012). Systems based on this concept have been industrially implemented in South Africa to optimise road maintenance from a cost perspective but is equally applicable for optimisation from a health and comfort perspective.

#### 16.5.1.2 Vehicle Activity

Vehicle activity can have a major effect on vibration exposure for operators and passengers. Mining equipment is usually selected for its suitability for the task at hand, its cost, robustness, power and maintainability. Very often these types of mobile equipment do not have effective suspension systems. This may often also be combined with poor ergonomics that require twisting and turning of the operator. Human comfort is often not included in these selection criteria. Since space is often very limited, a combination of approaches may be required to deal with problems like these. These may include measures such as: Improve the lighting of roadways so that operators may avoid unnecessary potholes, or unexpected rough road
conditions; visible or audible feedback to drivers to locate vehicles with respect to other vehicles (associated to current crash prevention initiatives), improved task design, and improved blasting standards to reduce rough work due to bad blasting.

Vehicle condition may of course also be intimately related to maintenance condition of equipment. In this regard continuous development in terms of on-board condition monitoring and fault reporting is becoming increasingly important.

In addition to space constraints (which may become extreme in the design of low-profile mining equipment like LHDs and continuous miners, vibration attenuation in mining vehicles is often problematic for other reasons too. Rubber suspension components are for example often not resistant to oil. They are also prone to aging at high working temperatures which leads to a decrease in vibration isolation performance (Xiao et al., 2020).

16.5.1.3 Engine Vibration

Engine vibration generally is a lesser problem and probably of lower importance in the mining environment.

16.5.2 Hand-arm Vibration

HAV is a difficult problem to resolve. It is known that rock drill vibration is one of the major contributors to high levels of hand-arm vibration in the mining industry. An obvious way to deal with this issue is using mechanised drilling machines. This trend is indeed noticeable and will be affecting the HAV landscape in South Africa for the foreseeable future. In South Africa it is however expected that manually operated drills will continue to be used for some years and in specific applications.
17 IMPACT OF VIBRATIONS ON EMPLOYEES

17.1 THE DATABASE

The impact of vibration was comprehensively considered and documented. The broad argument is however presented here.

To allow systematic investigations of the vibration data and its dependencies on parameters such as equipment type, power source, capacity, commodity, etc., a central Excel based repository was developed to serve as a vibration database that could be systematically interrogated and the results plotted, using MATLAB software.

The database was constructed in such a way that it could be used to unify data from very diverse sources into a common repository that makes it possible to plot all the data on common 2-dimensional or 3-dimensional axes. These plots for example allow investigations to compare vibration levels for related activities and for various equipment types.

17.1.1 Classification of mining equipment

To allow automated investigations of the data it was required to compile a classification scheme for the equipment under consideration. A common scheme is used for the noise and noise vibration parts of the project. This scheme is shown in Figure 20 below. In essence one distinguishes between plant, surface and underground equipment. Plant equipment refers to those that are typically found in workshops at mines (such as grinders and hand drills). Surface refers to equipment found on surface such as for the hauling of material. Underground refers to equipment found in underground operations, such as rock drills.

On each level equipment is classified as handheld, semi-stationary, stationary, trackless or track bound. Each of these equipment classes are further subdivided into equipment as shown in Figure 21. Further classification into different configuration categories is then possible if required (see Figure 22 for underground handheld rock drills).

![Figure 20: Equipment classification](image)
Figure 21: Underground equipment classes and types

Figure 22: Underground handheld rock drill configuration categories
17.1.2 Database structure

The database comprises an Excel spreadsheet with file name MHSC SAMI OEL Database Year-Month-Day.xlsx with separate sheets for whole-body vibration (WBV) and hand-arm vibration (HAV) data. There are two more sheets that can be used to calculate the Vibration Dose Values (VDV calc) and the A(8) values (A(8) calc) respectively, depending on the data available from the different literature sources. Data fields used in the database are given in Table 24:

Table 24: Data fields

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>WBV, HAV</td>
</tr>
<tr>
<td>Publication date</td>
<td>WBV, HAV</td>
</tr>
<tr>
<td>Commodity</td>
<td>WBV, HAV</td>
</tr>
<tr>
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<td>WBV, HAV</td>
</tr>
<tr>
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<td>WBV, HAV</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>Model</td>
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</tr>
<tr>
<td>Capacity</td>
<td>WBV, HAV</td>
</tr>
<tr>
<td>Mine</td>
<td>WBV, HAV</td>
</tr>
<tr>
<td>Country</td>
<td>WBV, HAV</td>
</tr>
<tr>
<td>A(8)</td>
<td>WBV, HAV</td>
</tr>
<tr>
<td>VDV(8)</td>
<td>WBV</td>
</tr>
<tr>
<td>a&lt;sub&gt;v&lt;/sub&gt;</td>
<td>HAV</td>
</tr>
<tr>
<td>Exposure time</td>
<td>WBV, HAV</td>
</tr>
</tbody>
</table>

17.1.3 Algorithm

The algorithm flow diagram is shown in Figure 23 and applies to both WBV and HAV vibration databases. The algorithm was coded to facilitate automated analysis by specifying data selection criteria based on five parameters namely commodity, location, equipment classification, equipment type and equipment configuration.

This approach is geared towards allowing access to the database and results via a graphical user interface (GUI). Such a GUI was however not developed as part of the present project, because of the large number of investigations that were done and the fact that it was simply easier for the purposes of this project to do these investigations directly via MATLAB. It is however suggested that such a GUI could easily be developed in a follow-up project, to make the database readily accessible for people with no MATLAB programming background.

As the database grows, further selection criteria could be included, such as year of measurement, machine size or power source, etc. After loading the raw data and analysis parameters, the data is sorted according to the selection criteria, and statistical analysis conducted.
17.2 A SYSTEMATIC INVESTIGATION OF THE EFFECTS OF VIBRATION ON SAMI EMPLOYEES

17.2.1 Introduction

Because South Africa does not have formal occupational vibration exposure limits (OELs) in place, vibration exposure levels and exposure times are generally not widely reported. The little available data was however collated in the common database as is described in this section. This database was then interrogated to provide evidence to address a number of key questions which are relevant to determining the desirability of vibration OELs for South Africa, and the levels at which such limits should be set if it would be decided to introduce vibration OELs in South Africa.

17.2.2 Whole-body vibration

Whole-body vibration occurs commonly in the SAMI, very often in wheeled mobile equipment. There are however also situations where the equipment is essentially stationary, while still exposing operators to significant vibration. Drill rigs are examples of this.

Figure 24 depicts vibration expressed in terms of A(8) and VDV values for the range of equipment that has been included in the database.

In Figure 24 A(8) and VDV are plotted as functions of the sample number percentage. The sample number percentage normalises the number of measurements taken for each piece of equipment to 100 percent. This implies that if results for only one piece of equipment has been captured in the database (such as a front end loader - FEL), that single vibration value will be plotted at 100% of sample number percentage. If many representative measurements of a particular equipment type have been captured, they show up as many numbers plotted over the range 0 to 100%.
Figure 24: A(8) and VDV as functions of sample number percentage
The rationale behind this representation of the data is to highlight different strata of measurements corresponding to similar types of equipment, while at the same time giving the reader a sense of how much data there is associated with each type of equipment, and therefore also a sense of the consistency of the data.

It is clear from Figure 24 that by far the bulk of the whole-body vibration measurements are below the EU Directive 1.25 m/s² A(8) level. This conclusion is reinforced by Figure 24 which shows the number of measurements as a function of acceleration level. It is however also clear from Figure 25 which has been extracted from ISO 2631, that for a 4 to 8 hour work period this may well reach the caution zone. There is some degree of inconsistency between the ISO 2631 standard and the EU Directive (see Forster, 2007).

![Figure 25: ISO 2631 caution and health risk zones](image)

Dozer and especially drill rig measurements do exceed 1 m/s² and some caution clearly needs to be exercised in terms of monitoring these groups of equipment. The EU Directive 2002/44/EC considers 1.15 m/s² as the exposure limit value. It is again clear that dozers could, and it is certain drill rigs typically do, exceed these levels.

While load haul dump (LHDs) trucks are generally associated with low levels of vibration, there is a small subgroup of LHDs where vibration levels can on average be of the order of 4 m/s². These very high observations were primarily reported by Wolfgang and Burgess-Limerick in an Australian study and Mayton et al. (2018) in an American study. A few very high observations were also made on an FEL and a shovel.

The EU directive specifies 17 m/s² is the limit for the VDV. On this criterion there is a larger proportion of measurement samples that exceed the limit. VDV is particularly sensitive to peak values in the vibration signal since the acceleration is raised to the power 4.
17.2.2.1 South African measurements compared to internationally reported vibration levels

In our investigations we have distinguished between whole-body vibration levels measured at South African mining sites, and internationally reported vibration levels. It was clear that the very high vibration levels were reported for international sites.

With the exception of one measurement point at $A(8) > 3$ and $VDV > 50$ the South African whole-body vibrations are essentially within the EU Directive limits.

17.2.2.2 The effect of introduction of new technology in the vibration of mining machinery

An attempt was made to determine if the introduction of more sophisticated technology affected vibration levels in mining equipment over the last two decades.

Since the date of the measurement was very difficult to determine in most cases, and the date of manufacture of the specific mining equipment, was even more difficult to account for, the publication date of reported vibration levels was used as a very rough proxy for determining the impact of modern technology over time.

It is important to note that there are some significant outliers in the values. This was especially the case for vibration values were in the Australian study which was previously mentioned (Wolfgang and Burgess-Limerick, 2014).

It does however seem as if there is not a specific trend to be observed with publication date. From this we surmise that there is not enough evidence to conclude that the introduction of technology has led to either a significant reduction or increase in vibration levels over the past two decades. If anything, vibration levels have deteriorated somewhat.

17.2.2.3 Effect of surface haul truck payload

To try and capture aspects related to the scale of mining operations, the vibration $A(8)$ and $VDV$ values were investigated as function of truck payload. An interesting observation from this investigation is the fact that vibration levels on most of these trucks typically comply with the 1.25 m/s$^2$ vibration limit specified in EU Directive 2002/44/EC.

It should however be observed that in the 100 to 200-ton range there are a number of trucks that significantly exceed the EU Directive limit. Most of these are dump trucks that are used in coal mining and these results have been reported by Wolfgang and Burgess-Limerick (2014). This may suggest that vibration levels do not necessarily scale up with payload and could imply that vibration levels on trucks might be more severe on some smaller trucks.

17.2.2.4 Compensability of whole-body vibration

There is strong epidemiological evidence for a relationship between occupational exposure to whole-body vibration and low back pain (Hulshof et al., 2019). There does however seem to be very little evidence of successful whole-body vibration compensation claims in the mining industry at large.
17.2.2.5 Broad conclusions from the whole-body vibration data
A number of simple but powerful conclusions can be reached:

- While the whole-body vibration levels in the SAMI does approach caution levels in some cases (ISO 2631) and has exceed the EU limits in one case, whole-body vibration levels in the SAMI are generally not excessively high.

- Although low back pain (LBP) is recognised by a few European countries as a compensable disease (Hulshof, 2002), it seems as if internationally accepted criteria have not yet been established. The authors could also not find significant evidence of successful whole-body vibration compensation claims in the world.

- Whole-body vibration levels are not widely reported for the mining industry during normal operations. Most of the measurement results that were obtained were for specially commissioned studies. This is not quite surprising since the measurement of vibration levels in robust and dirty conditions is quite difficult. This is partly because most vibration measurements nowadays still require a cable connection to a three-axis accelerometer. This situation might change as wireless accelerometers become more common in future.

- South African whole-body vibration exposures seem to be, if anything, lower or at least comparable to vibration measurements that have been reported at international mining sites.

- Given the limited evidence that we could muster, it does not seem as if technology has played a significant role in either increasing or decreasing vibration exposure levels over the past two decades. It is unlikely that this will change in the near future, unless the regulatory environment changes.

- There is some evidence to believe that trucks with payloads between 100 and 200 ton may vibrate more significantly than other trucks. It must be emphasised that most of these measurements were not conducted in South Africa.

17.2.3 Hand-arm Vibration
Hand-arm vibration is also quite common in the SAMI. This is normally associated with hand-held equipment.

Plant equipment like grinders and hand drills are very commonly found in workshops at mines. In the underground environment rock drills are the most common hand held equipment.

While the effects of hand transmitted vibration on humans present themselves in different ways. These include vascular as well as neurological effects. Comprehensive work has been done to assess these effects as well as to develop criteria for compensation.

Hand transmitted vibration is usually expressed in terms of $a_{hv}$ and $A(8)$ values. As was the case for whole-body vibration, these parameters were comprehensively defined previously. Figure 26 depicts measured hand transmitted vibration expressed in terms of $a_{hv}$ and $A(8)$ values for the range of equipment that has been included in the database.

For hand-arm vibration it is also clear that the data is roughly stratified according to the type of equipment involved. The scatter is however significantly higher than for the whole-body vibration. This is probably because hand transmitted vibration is particularly dependent on the
way the equipment is operated, the rock conditions in case of rock drills, or the operations involved in plant equipment.

Grinders typically correspond to A(8) vibration levels of below 5 m/s² while impact tools cause A(8) vibration levels around 5 m/s². On the other extreme descaler needle hammers cause very high levels of vibration which are typically of the order of 20+ m/s². The rock drill is also very high with typical A(8) values in excess of 15 m/s² and in a number of cases approaching 30 m/s².

Bearing in mind that 1.25 m/s² represents the EU Directive 2002/44/EC HAV action level value, and 5 m/s² represents the EU Directive 2002/44/EC HAV limit, it is clear that HAV represents a significant problem in mining.

While the use of scalers were reported by Burns (2004) for operations in Namibia, rock drills are very commonly used in the SAMI.

The study by Nyantumbu et al. (2010) provided evidence that a significant percentage of South African rock drill operators suffer from hand-arm vibration syndrome. For calculation of the South African A(8) values for hand transmitted vibration, it was assumed that typical rock drill vibration exposure time is 4 hours. There is uncertainty around this value. In practice rock drill operators are assisted by the pressure in the jackleg. While the jackleg is used to apply the bulk of the thrust during the drilling process, the operator must still guide the drill, and is still exposed to vibration. It must however be realised that the operator does not necessarily grip the drill tightly. This may reduce the transmission of vibration.
Figure 26: Typical $a_{nv}$ and $A(8)$ vibration levels for hand-held vibration equipment
If $a_{th}$ and $A(8)$ vibration levels for hand-held vibration equipment are classified according to the categories plant, surface and underground, it seems as if vibration levels are very high in the plant, surface and underground applications. This is caused to a large extent by very high levels for plant and surface equipment reported in the Italian Physical Agents Portal https://www.portaleagentifisici.it/?lg=EN.

Comparing vibration levels measured in South Africa to internationally reported vibration levels, it is again observed that reported South African vibration levels are generally lower than vibration levels reported in various international studies.

South African and internationally reported levels however both far exceed the EU Directives for hand-arm vibration syndrome. A more detailed analysis of the data however suggests that in South African mines the offending equipment is largely rock drills.

Using publication date as a proxy for the effect of new technology on hand transmitted vibration, it seems that, if anything, the vibration levels seem to slightly increase with time. It can safely be concluded that vibration levels on handheld equipment do not seem to be reducing over time.

If one distinguishes between pneumatic, hydraulic, and electrical drills, it is clear that vibration data is most readily available for pneumatic rock drills. Typical $A(8)$ vibration levels for these drill range from $5 \text{ m/s}^2$ to $35 \text{ m/s}^2$.

From analysis of the data in the database it is known that for South African pneumatic rock drills the $A(8)$ values are typically in excess of $25 \text{ m/s}^2$. Although measurements for hydraulic rock drills are much less readily available, it is also known that these levels can be as high as $30+ \text{ m/s}^2$. Vibration levels for electrical drills are typically much lower at less than $10 \text{ m/s}^2$. Even these much lower values however still exceed the EU Directive limit values.

While electrical drills are much more recent than the pneumatic drills, which have been around since the 1850s, and hydraulic drills which date back at least as far as the 1970s, it also known that the penetration rates of electrical rock drills do not compare well with pneumatic and hydraulic drills.

This is relevant in the context that it is unlikely that new technology will soon lead to development of rock drills that operate at much lower vibration levels.

### 17.2.3.1 Broad conclusions from the hand-arm vibration data

A number of simple but powerful conclusions can be made:

- Hand-arm vibration levels significantly exceed the EU limits in all cases and are excessively high.
- Hand-arm vibration syndrome is a compensable disease. Criteria to assess hand-arm vibration syndrome are internationally well-developed. Multiple successful compensation claims have been lodged in the world. The best-known example is probably in the case of claims against British Coal.
- Hand-arm vibration levels do not seem to be generally recorded in the mining industry during normal operations. Most of the measurement results that were obtained were for specially commissioned studies.
- South African hand-arm vibration exposures seem to be, if anything, lower than some vibration measurements that have been reported at international mines. It is however
important to point out that the use of hand-held equipment such as rock drills seems to be on the decline.

- Given the limited evidence that we could gather, it does not seem as if technology has played a significant role in either increasing or decreasing vibration exposure levels over the past two decades. It is unlikely that this will change in the near future, unless the regulatory environment changes. It is however expected that mechanisation will play an important role in the reduction of the number of rock drill operators that use hand-held drills.

### 17.2.4 Implications of changes in technology

In the literature review attention was given to a number of interesting technological advances in the realms of human vibration attenuation and control in whole-body and hand-transmitted vibration were discussed. None of these developments are however likely to cause major changes in human vibration levels in the near future.

In this report a brief investigation was done to see if there were any significant changes in vibration levels in whole-body vibration as well as hand transmitted applications. No significant trends could be observed.

The authors believe that continuation of mining operations using essentially present mining technologies will not lead to significantly reduced vibration levels being observed for whole-body vibration and hand transmitted vibration. Pressures to reduce the mining height, might however potentially increase whole-body vibration levels in vehicles used in such applications (it is worth noting that the pressures to reduce mining height are in most cases in-stope, and not in access/travelling roads and haulages) With reduction in mining height the potential vertical travel of vehicle suspension to attenuate the vibration levels, is likely to reduce. This has direct consequences for the potential of the suspension system to reduce the vibrations transmitted to human operators and passengers while travelling. At the same time distances to the work areas are increasing which implies pressure to travel faster, which again increases vibration.

In the case of hand-transmitted vibration it is clear that vibration levels are already excessive, and even new approaches to drilling, such as electrical drills, do not provide simple solutions. In this context the expected increasing mechanisation of mining obviously plays a potentially important role.

Another important technological development is the rapid development towards wearable sensors and recoding of signals such as vibration signals.

Combined with wireless sensing which will allow the measurement of vibration without the need to link the vibrating structure to the recording device, will in future allow mine management to monitor vibration exposure continuously. Through this sort of dosimetry, it will also become possible to manage vibration exposure much more effectively, and potentially rotate operators to reduce their long-term exposure.

### 17.2.5 Vibration and social-well-being

Human vibration, especially HAV, is a multidimensional occupational disease associated with overlapping vascular, neurological, and musculoskeletal symptoms. While the underlying mechanisms are multidimensional, it is common in the study of human vibration to consider
the effects of vibration on the human body as a collective of all these effects simultaneously, and occupational exposure is generally not linked to a specific mechanism such as vascular, neurological or musculoskeletal effects. The vibration levels reported in the study above therefore have to be interpreted as contributing to deterioration of human quality of life due to all of these effects simultaneously.

An aspect of the effect of vibration of human beings, which has received less attention in the literature, is the impact of the lived experience on people who are suffering from WBV or HAV. In one of the few studies that addresses this, Ayers and Forshaw (2010) find that HAVS can lead to a withdrawal from social activities as well as feelings of frustration and isolation. Individuals suffering from HAVS are therefore not only affected physically, but also psychologically. They conclude that an interaction of psychological factors, machismo, and the fear of losing employment lead to reluctance to report HAVS to managers and health professionals. This could of course complicate the implementation of health management programs.

Handford et al. (2017) reinforce these findings. They also point to a dearth of qualitative research on the subject and encourage further research to explore the perceived effects of HAVS on daily life.

It is clear that the lived experiences and psychological effects of human vibration have not received much attention in the international literature at all. No South African studies on this were found. It can only be surmised that this may just be one more factor that contribute to frustration, fear and uncertainty in the SAMI in a community that already suffer from poor social and economic conditions.

17.2.6 Gender considerations in human vibration

Various studies of the effect of vibration on humans have considered very different groups of test subjects. In an early review study, Wikström et al. (1994) considered whole body vibration studies conducted on about 18 000 exposed subjects in 45 different studies. They reported that the mean age for these studies varied between 23 and 52 years of age. In 25 of these studies only men were included in the exposed groups, in 5 studies only women, in 4 studies men and women, while in 11 studies sex is not given.

It is clear that the majority of studies have been conducted on males, but that some females have also been included. It can safely be assumed that many of these studies found their way into the experimental results that were used to develop the ISO Standards that are currently used for the assessment of human vibration (see for example Chapter 10 of Griffin’s authoritative Handbook of Human vibration.) It can therefore be surmised that current standards are based on experimental data obtained from studies on males and females. The present day ISO standards therefore do not distinguish between males and females in the measurement or the assessment of human vibration.

It is however very clear that women who are exposed to whole body vibration may suffer from increased levels of uro-genital disorders (Wikström et al., 1994). Southon (2010) studied the effects of human vibration on underground locomotive drivers and recommended that special precautionary measures be taken in deploying women as locomotive operators, especially during their child bearing years. Berezan et al. (2004) indicate increased caution with pregnant women driving haul trucks.
In a very interesting investigation, Marjanen (2010) explored the use of the ISO 2631-1 standard for evaluating discomfort from whole-body vibration in male and female groups. This study suggests that there are no significant differences between judgement of vibration related discomfort between men and women. It is concluded that neither gender nor physical dimensions affect the person’s judgement of discomfort. Subjective assessment of discomfort is of course no indication of actual harm, but it is at least consistent with the way in which current standards do not make a distinction between males and females.

It is also interesting to note that a comprehensive study by the US Bureau of Labor Statistics, indicated that occupational exposure to whole-body and hand-arm vibration and awkward posture is significantly associated with musculoskeletal disorders of especially the shoulder and neck. The incidence rate of musculoskeletal disorders is somewhat higher among male workers (37.5 per 10 000 full time workers) as opposed to female workers in the general working population (29.7 per 10 000 full time workers) (Charles et al., 2018). It is not clear to what extent this effect is due more to vibration or posture.

It is also clear from the literature that males are generally more exposed to vibration than females. In a recent Swedish study it was estimated that 14% of all employed men and 3% of women are exposed to vibration from hand-held machinery for at least 25% of their working time (Carra, 2019).

The authors however believe that there is currently no reason to believe that the differences between the sexes should be dealt with different control measures. An important exception to this rule would be to recommend that vibration exposure of pregnant women should be minimised.

### 17.2.7 General conclusions

While whole-body vibration and hand-transmitted vibration are both important physical stressors and both classes of vibration problems need to be carefully considered in the SAMI, a number of general conclusions can be reached at this stage:

- Whole-body vibration is reaching cautionary levels in the SAMI.
- Criteria to assess the negative consequences of whole-body vibration are not well developed and there seems to be very few successful WBV related claims in the world.
- Hand transmitted vibration is a significant problem in the SAMI.
- There are well-developed criteria to assess the effect of hand-transmitted vibration. There have been multiple successful compensation claims for hand-arm vibration syndrome.
- Vibration levels are unlikely to reduce unless the regulatory framework changes.
- Technological advances related to sensors and wireless vibration monitoring could simplify the management of human vibration exposure in future.
- Social well-being is adversely affecting by the effects of human vibration. This effect has however not been quantified internationally, and also not in South Africa.
- Special care should be taken when exposing pregnant women to vibration.
17.3 FINANCIAL COST ANALYSIS

This section provides an overview of the developed financial model associated with MHSC CoE 180701, along with the cost determination associated with the current vibration exposure as well as the cost impact of a revised vibration exposure limit. The financial model presented, and the derived financial implication which has been determined based on this financial model, represents an approximation of the true cost associated with both the current, and revised, vibration exposure levels. It is noted that while every effort has been made to determine the most accurate costing implications, assumptions needed to be made based on the availability of information.

The cost determination presented in this study is partly based on that done in by the US OSHA, Department of Labour (Occupational Exposure to Respirable Crystalline Silica, Final rule., 2016). That being, as the financial implications will arise over an extended period of time, these future costs and future benefits will be presented in an annualised format using a present value of future costs technique.

17.3.1.1 Cost Determination

The cost determination must be broken down into the varying cost categories, namely:

- Monitoring mineworker exposure; and
- Measuring financial impact of the mineworker exposure.

The financial model has developed a framework which estimates the future financial costs (associated with both the current mineworker exposure as well as the exposure under revised exposure limits) for each of the cost categories as outlined in Table 25 below.

17.3.1.2 Financial Model HAVS Cost Equation(s)

The cost equation(s) of this particular study, and the description of these elements, is shown, for reference, in Table 25 below:

Table 25: Cost Equation(s)

<table>
<thead>
<tr>
<th>COST EQUATION</th>
<th>COST, BENEFIT &amp; DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Equation 1} = Ces + Ceu + Cms + Cmu )</td>
<td><strong>COSTS</strong> relating to:</td>
</tr>
<tr>
<td></td>
<td>1) Exposure monitoring ((Ces &amp; Ceu))</td>
</tr>
<tr>
<td></td>
<td>2) Medical validation ((Cms &amp; Cmu))</td>
</tr>
<tr>
<td>( \text{Equation 2} = Cp + Cr + Ct + Ci + 0.72 \times Ci )</td>
<td><strong>COSTS</strong> relating to:</td>
</tr>
<tr>
<td></td>
<td>1) HAVS lump-sum pay-outs ((Cp));</td>
</tr>
<tr>
<td></td>
<td>2) Replacement workers ((Cr));</td>
</tr>
<tr>
<td></td>
<td>3) Training costs ((Ct));</td>
</tr>
<tr>
<td></td>
<td>4) Incident investigations ((Ci)); and</td>
</tr>
<tr>
<td></td>
<td>5) Lost earnings ((Cl)).</td>
</tr>
</tbody>
</table>

Note: The above computational equations are based on a South African corporate tax rate of 28%. More details on this, along with other assumptions included in the model, is provided in sections that follow.

17.3.2 Methodology

The financial model was run in two separate iterations, namely:
1) The cost associated with the current vibration exposure; and
2) The cost associated with vibration exposure (and its related monitoring) under a revised exposure limit.

The financial model methodology, along with the various assumptions made, associated with each of the cost elements highlighted in the cost equation(s) 1 and 2 are available upon request.

**17.3.3 Results**

**17.3.3.1 Iteration 1: Cost associated with current vibration exposure**

The result of the financial analysis indicated a total financial impact of R 36 734 526, as shown in Figure 27.

<table>
<thead>
<tr>
<th>TOTAL FINANCIAL IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNUALISED FINANCIAL COST - ASSOCIATED WITH COMPENSATION &amp; HEALTHCARE</td>
</tr>
<tr>
<td><strong>HAND ARM VIBRATION SYMPTOMS (HAVS) LUMP SUM PAYOUTS</strong></td>
</tr>
<tr>
<td>R -</td>
</tr>
<tr>
<td>R -</td>
</tr>
<tr>
<td><strong>HAND ARM VIBRATION SYMPTOMS (HAVS) REPLACEMENT COSTS</strong></td>
</tr>
<tr>
<td>R 7 270 273</td>
</tr>
<tr>
<td>R 7 270 273</td>
</tr>
<tr>
<td><strong>OTHER INDIRECT COSTS</strong></td>
</tr>
<tr>
<td>R 29 464 253</td>
</tr>
<tr>
<td>R 5 824 779</td>
</tr>
<tr>
<td>R 11 649 558</td>
</tr>
<tr>
<td>R 11 989 916</td>
</tr>
<tr>
<td><strong>TOTAL ANNUAL FINANCIAL COST</strong></td>
</tr>
<tr>
<td>Cp + Cr + Ci + Ct + Cl x 0.72</td>
</tr>
<tr>
<td>R 36 734 526</td>
</tr>
</tbody>
</table>

*Figure 27: Total financial impact associated with the current level of noise exposure*

The biggest contributing factors to the total financial impact was that of the indirect costs attributable to a reduced output and training. When combined, these two cost elements made up 64.3% of the overall financial impact.

**17.3.3.1.1 HAVS lump sum pay-outs**

Importantly, as a result of no historical information relating to pay-outs in South Africa, no cost associated with lump-sum payments could be forecast / included into the financial analysis.

**17.3.3.1.2 Reduction in ‘output’**

The reduction in output results in an annualised cost of approximately R 11 989 916. This cost is directly linked to key assumptions relating to the output multiplier, the diagnosis period and the South African corporate tax rate.

**17.3.3.1.3 Training Costs**

The total training cost was estimated to result in an annualised cost of approximately R 11 649 558. This was based on a forecasted total of 46 598 mineworkers being impacted over a prevailing 30 year period.
17.3.3.2 Iteration 2: Cost impact associated with an exposure limit put into place

The result of the financial analysis indicated a total financial impact of R 1 197 739 394 when a vibration exposure limit is put into place, as shown in Figure 28.

<table>
<thead>
<tr>
<th>TOTAL FINANCIAL IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNUALISED COSTS - ASSOCIATED WITH LIMITING EXPOSURE, TESTING EXPOSURE</td>
</tr>
<tr>
<td>EXPOSURE MONITORING COSTS</td>
</tr>
<tr>
<td>- SURFACE MINES</td>
</tr>
<tr>
<td>- UNDERGROUND MINES</td>
</tr>
<tr>
<td>MEDICAL VALIDATION COSTS</td>
</tr>
<tr>
<td>- SURFACE MINES</td>
</tr>
<tr>
<td>- UNDERGROUND MINES</td>
</tr>
<tr>
<td>TOTAL ANNUAL FINANCIAL COST (PHASE 1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ANNUALISED FINANCIAL COST - ASSOCIATED WITH COMPENSATION &amp; HEALTHCARE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAND ARM VIBRATION SYMPTOMS (HAVS) LUMP SUM PAYOUTS</td>
</tr>
<tr>
<td>- HAVS</td>
</tr>
<tr>
<td>HAND ARM VIBRATION SYMPTOMS (HAVS) REPLACEMENT COSTS</td>
</tr>
<tr>
<td>- HAVS</td>
</tr>
<tr>
<td>OTHER INDIRECT COSTS</td>
</tr>
<tr>
<td>- Investigation Cost(s)</td>
</tr>
<tr>
<td>- Training Costs</td>
</tr>
<tr>
<td>- Reduction in ‘output’</td>
</tr>
<tr>
<td>TOTAL ANNUAL FINANCIAL COST (PHASE 2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL ANNUAL FINANCIAL COST *</td>
</tr>
<tr>
<td>*Cost associated with a more stringent vibration exposure limit</td>
</tr>
</tbody>
</table>

Figure 28: Total financial impact associated with the current level of noise exposure

The biggest contributing factors to the total financial impact was that of the indirect costs attributable to medical surveillance costs. This cost element, alone, makes up 97.5% of the overall financial impact.

17.3.3.2.1 Medical surveillance costs

The large medical surveillance costs relate to both the ‘cost to each mine’ as well as the large number of mines which are presently operational in South Africa. Significant contributors to this overall cost, by means of cost element, included the cost associated with the risk assessment, incident investigations and additional medical tests requiring to be performed.

17.3.3.2.2 Annualised cost associated with compensation and healthcare

The total annualised cost associated with compensation and healthcare has reduced, in comparison to iteration 1. However, owing to both the limited data and lack of “claim ability” of vibration exposure on mineworkers, this cost element is not substantial enough to meaningfully offset the increase associated with a medical surveillance cost.
17.3.4 Conclusions

The results of this financial assessment indicate a very substantial increase in the total cost of the mining industry as a result of introducing vibration OELs, with the annual cost to the mining industry estimated to increase by approximately R1.16 billion annually. To put this number in some perspective, in 2018 the mining sector contributed R351 billion to the South African Gross Domestic product (GDP) (Minerals Council, 2018). The projected cost therefore translates to roughly 0.33% of the mining sector contribution.

Based on the financial computation, the cost associated with the 'revised' VIBRATION exposure is determined (based on the assumptions above) to approximate:

| TOTAL ANNUAL COST | R 1 197 739 394 |

The financial cost associated with the current VIBRATION exposure (before any exposure limited) as determined in Milestone 4, was determined to approximate:

| TOTAL ANNUAL COST | R 36 734 526 |

As such, the delta rand (i.e. the incremental benefit / (cost) as a result of introducing a vibration exposure limit) is determined to be:

| ANNUAL (NET) FINANCIAL IMPACT | -R 1 161 004 868 | Financial Cost |

Figure 29: Summary of Total Annual Financial Cost
18 RELEVANCE AND APPLICABILITY OF VIBRATION OELS

A virtual workshop was held with invited members of the SAMI in order to review the relevance and applicability of vibration OELs. The members from the SAMI comprised of members from organised labour, employers and state (as per demographic breakdown in Section 14). It is of course recognised that this is a limited sample of people, not necessarily representative of the entire industry and will undoubtedly introduce bias. This was however a serious attempt to broaden input beyond the immediate sphere of influence of the team.

Participants to the workshop were presented with preliminary results from previous milestones of this project, through the Google Meet platform. The participants were then asked to contribute to the discussion by answering some leading questions, followed by an opportunity to motivate their answers.

A total of 52 participants were involved (demographic of the group as shown in Section 14) in the discussion and an average of 79% of these participants engaged with the project team, through the PollEV platform.

The question categories and individual questions are shown in Table 26, and the feedback on the questions are shown in Figure 30.

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<thead>
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<th>Table 26: Categories of questions and Individual Questions asked</th>
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<tr>
<td><strong>Category</strong></td>
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<td>Vibration OELs and International Approaches</td>
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<td>Importance of HAV and WBV</td>
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<td>Vibration Exposure</td>
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Figure 30: Responses to questions posed to workshop participants
19 PROPOSED VIBRATION OELS AND ASSOCIATED GUIDANCE NOTES

19.1 OCCUPATIONAL EXPOSURE LIMITS FOR VIBRATION

19.1.1 Rationale

19.1.1.1 The case for introducing vibration OELs in the SAMI

It is clear from the studies conducted for this project that human vibration levels in the international and South African mining industries are high.

From the international literature on human vibration it is evident that human vibration has and is still receiving significant attention in the literature. The publication of human vibration standards (ISO 2631 and ISO 5349) and the European Directive 2002/44/EC made a huge impact in the field and have shaped the international response to human vibration to a very significant extent. The American Conference of Governmental Hygienists (ACGIH) has also been influential – primarily so on the American continent.

It is however clear that human vibration remains a continuing problem in the world.

Our investigation of the effect of vibration on employees in the South African Mining Industry, also compared these impacts with international observations. As is usually done with human vibration, this study also distinguished between whole-body vibration (WBV) and hand-arm vibration (HAV).

For whole-body vibration it was concluded that:

- Although whole-body vibration (WBV) levels in the SAMI are generally not excessively high, WBV levels in the SAMI does approach caution levels in some cases and occasionally exceed EU limits. This situation might in future deteriorate because of spatial restriction in mining lower seam heights.

- Although low back pain (LBP) is recognised by a few European countries as a compensable disease (Hulshof et al., 2002), it seems as if internationally accepted criteria have not yet been established.

- WBV levels are not widely reported for the mining industry during normal operations. Most of the measurement results that were obtained were for specially commissioned studies. This is not quite surprising since the measurement of vibration levels in robust and dirty conditions is quite difficult. This may become easier in future.

- South African whole-body vibration exposures seem to more or less comparable to vibration measurements that have been reported at international mining sites.

- Given the limited evidence that could be mustered, it does not seem as if technology has played a significant role in either increasing or decreasing vibration exposure levels over the past two decades. It is unlikely that this will change in the near future, unless the regulatory environment changes.

- For hand-arm vibration the following conclusions were reached:

  - HAV levels significantly exceed the EU limits in all cases and are excessively high.
- Hand-arm vibration syndrome is a compensable disease in various countries abroad. Criteria to assess hand-arm vibration syndrome are internationally well-developed. Multiple successful compensation claims have been lodged in the world.

- Hand-arm vibration levels do not seem to be generally recorded in the mining industry during normal operations. Most of the measurement results that were obtained were for specially commissioned studies.

- South African hand-arm vibration exposures seem to be, if anything, lower than some vibration measurements that have been reported at international mines. Hand-held rock drill operators in the SAMI are exposed to high levels of hand-arm vibration, however it is important to point out that the use of hand-held equipment such a rock drills seems to be on the decline.

- Given the limited evidence that could be gathered, it does not seem as if technology has played a significant role in either increasing or decreasing vibration exposure levels over the past two decades. It is unlikely that this will change in the near future, unless the regulatory environment changes. It is however expected that mechanisation may play an important role in the reduction of the number of rock drill operators that use hand-held drills.

In addition to the above it is known that an estimated 15% of South African rock drill operators do suffer from the effects of hand-arm vibration syndrome. Although this study was conducted on a relatively small group of around 300 people, it does at least confirm that there are a significant number of SAMI employees that suffer irreversible health consequences due to HAV.

It was therefore not surprising that the vast majority of participants in a workshop that was arranged to gauge industry sentiments toward the introduction of occupational exposure limits for vibration, shared the sentiment that the effects of human vibration are visible in the SAMI, and that human vibration in the SAMI should be regulated through appropriate OELs.

From the above it is clear that the introduction of vibration OELs in the SAMI are appropriate.

**19.1.1.2 A suitable benchmark for South African vibration OELs**

The development of OELs must obviously draw on standardised measurement and assessment methodologies. The ISO 2631 and ISO 5349 standards have become the de facto measurement standards. As a matter of fact, ISO 2631 has also resulted in SANS 2631 being adopted in South Africa as the whole-body vibration standard. This is not the case yet for ISO 5349, but it is reasonable to assume this will happen once the need has been established. Following the ISO standards is therefore essentially a given.

For assessment of the effects of vibration on the human body, the situation is more complex. As was discussed in the previous section there are two main international benchmarks with respect to vibration OELs, namely the European Directive and the American ACGIH. British scientists have been particularly prolific in their work on human vibration. The results of this work has been largely captured in the guidance developed by the UK Health and Safety Executive, which is well aligned with that of the European Directive. Australian practice is also well-aligned with European and British practices.

There are other human vibration initiatives in the world, notably in Japan and Korea. While there are some important differences, even these initiatives draw strongly from the European example.
Establishing such occupational exposure limits are however dependent on huge epidemiological studies from which appropriate assessment criteria were developed, based on data which were collected over decades. The European test subjects used for these studies can be assumed to have been conducted primarily on Caucasian test subjects. These studies have been widely reported on in the literature over several decades.

Formulation of the ACGIH assessment criteria has received much less attention in the literature, and the basis for exposure level-time tradeoffs does not seem to be well documented. They are also somewhat arbitrary in the sense that the same maximum allowed vibration level applies for exposure times of 8 hours and 4 hours. In Japan some slight corrections have been made in the exposure level-time tradeoffs compared to the European Directive, to account for Japanese workers as compared to Caucasian workers. While this might be tempting for South African OELs, there is however just far too little data available for South Africa to attempt to make such corrections for South African workers.

It was therefore decided to propose that South Africa essentially follows the European approach, but with a transition period to allow for the fact that South African HAV are just so high at the moment that the introduction and enforcement of OELs which are consistent with international practice, will summarily bring hand held mining operations in South Africa to a standstill.

For the practical implementation of these guidance notes in South Africa, standardised questionnaires will have to be developed for use in the clinic during the annual medical evaluations. It is envisaged that such questionnaires may be based on examples that have previously been developed, for example by Magnusson et al. (2001). These questionnaires are however too comprehensive for practical use and will have to be simplified.

19.1.1.3 A phased approach for HAV in South Africa

As was argued above, vibration levels associated with hand-held rock drill operations in South Africa are exceptionally high. The SAMI is unique in the world in terms of the extent to which hand-held rock drills are used during mining operations. This exposes rock drill operators in the SAMI to very high levels of vibration. In a study by Nyantumbu et al. (2007), it was shown that the prevalence of hand-arm vibration syndrome (HAVS) in vibration exposed gold miners was 15% with a mean latency period of 5.6 years. Among a non-exposed comparison group 5% had signs and symptoms indistinguishable from HAVS. This difference is statistically significant.

This prevalence is however lower than was expected as compared to what was found abroad for similar vibration levels. It is believed that this is partially due to a survivor population effect. Firstly, workers developing noise-induced hearing are continuously removed from removed from further drilling (vibration) exposures. Secondly, workers who have their grip strength reduced post-accidents, are also relocated.

It is further speculated that the warm ambient temperature in South African mines may also lead to reduced vascular symptoms associated with exposure to vibration. It is known from the medical literature that the prevalence of primary Raynaud phenomenon does vary with climate. It is therefore reasonable to assume that the prevalence of HAVS, which is also known as secondary Raynaud phenomenon, might also be affected by variations in climate. It must however be taken into account that primary Raynaud phenomenon is related to functional alterations in the body only. Secondary Raynaud phenomenon, in contrast, reflects structural microvascular abnormalities (Gayraud, 2007). Such conclusions will therefore require further
study to reach final conclusions. At the moment this does however look like a very reasonable explanation to explain observations in South African mines.

There is not nearly enough evidence to surmise that the fact that European studies have been conducted on Caucasian test subjects could play an important role in explaining the results. It is nevertheless clear that a significant proportion of South African rock drill operators do suffer from vibration induced HAVS. The problem cannot therefore be ignored.

Instituting the HAV occupational exposure limits adopted elsewhere in the world would however very severely disrupt SAMI operations and a phased approach is therefore proposed, to allow the industry to react to the challenge of reducing vibration exposure levels, either through the introduction of attenuation measures or through the introduction of measures to control exposure times.

Currently the European Directive mandates a HAV exposure limit value (ELV) of 5 m/s². This is not feasible for all with current equipment and work practices and would result in allowable working periods in the order of seconds or a few minutes, for typical rock drills. A level of 13 m/s² would allow rock drills operating at 28,8 m/s² a trigger time of 90 minutes a day. This is surprisingly high but is deemed a reasonable immediate target. In this context trigger time refers to the time that the equipment actually drills and requires the operator to control of the equipment by physically holding on to the equipment and apply force to the equipment.

It is proposed that a five-year period be allowed for the industry to manage this down to 5 m/s². It is anticipated that during the five-year period a very clear understanding of current rock drill vibration levels could be developed together with a very good understanding of actual trigger times.

It is known that HAV levels in South African Mines are excessive and the SAMI exposes larger numbers of rock drill operators these high levels than is typical elsewhere. Although the prevalence of HAVS is lower than expected (as argued above) we still know that HAVS occurs in around 15% of South African rock driller operators. This is not acceptable and must be changed. Ideally a very significant reduction of rock drill vibration exposure should be implemented immediately. It however very difficult to see even an ‘immediate’ transition to be implemented in less than two years.

On the other hand if there is no urgency it is clear that little will happen. By way of example: There was significant research done in South Africa on the reduction of rock drill vibration in the early 2000s, due to fears that something like the British Coal experience (see section 16.1) might repeat itself in South Africa. Once that fear dissipated because it became clear that South Africa did not plan to introduce vibration OELs in the foreseeable future, this development stopped very quickly.

From this perspective a ten year horizon is considered too long to initiate the immediate action required.

A five-year period is considered a tough but attainable target. This target will have to be reached by a combination of measures:

- Reduction of rock drill vibration transmitted to operators. Passive methods of rock drill vibration reduction (Marcotte, et al., 2008) can probably not bring the levels down sufficiently to comply with the proposed OELs. But they can contribute. More effective semi-active and active methods have been developed but are expensive and
cumbersome. And they still transmit fairly high levels of vibration to the human hand (Du Plooy, 2003). This is therefore probably not feasible to pursue at present as a short term solution. Vibration attenuation should therefore be expected to only provide a partial solution but, passive solutions should in principle be relatively simple to implement and will not require fundamental redesign of rock drills themselves.

- Attenuation of rock drill vibration will therefore have to be combined with changed drilling procedures to reduce human exposure to acceptable levels. This is in principle also possible to implement in a reasonable time frame.

**19.1.1.4 Cost implications of the introduction of vibration OELs**

Introducing OELs must imply that improved human health is balanced against cost implications. This is a very difficult ethical and social tradeoff due to the inherent difficulty in balancing human quality of life and health against monetary considerations.

It is however considered important to try and quantify the cost implications of introducing vibration OELs as best as possible. For this purpose, a very detailed cost model was developed as part of Milestone 4, to help inform future decisions to implement vibration OELs. This model has since been implemented in a comprehensive Excel spreadsheet and estimated costing details have been introduced in the model.

This model makes a number of very significant assumptions which combined can have very large implications for the cost estimate:

- Employee workforce remains constant at 2018 levels.
- A 10 day recovery period and 3 day lead time is assumed for vibration related complaints.
- A total of R 5000 investigation cost is assumed.
- Total training cost of R 10 000 with 100% retraining cost is assumed.
- An output multiplier of 5.18 is assumed for days lost.
- Mineworker staff costs of 5% are assumed.
- A discount rate of 8% is assumed.
- Of the workers affected 75% are assumed underground and 25% workers on surface.

The results of this financial assessment indicate a very substantial increase in the total cost of the mining industry as a result of introducing vibration OELs, with the annual cost to the mining industry estimated to increase by approximately R1.16 billion annually. To put this number in some perspective, in 2018 the mining sector contributed R351 billion to the South African Gross Domestic product (GDP) (Minerals Council, 2018). The projected cost therefore translates to roughly 0.33% of the overall mining sector contribution to the GDP. It must of course be realised that this number reflects turn-over and not profit, and is therefore very significant.

Another perspective on this number is to compare costs for noise induced hearing loss compensation in South Africa to vibration, as the physical stressor that probably resembles vibration the closest. The platinum industry in South Africa alone experienced a peak compensation payout of R 90 million in 2005 (Edwards and Kritzinger, 2012). Disregarding the
changes in the purchasing power of the Rand over the years, and the fact that noise compensation has since declined in Rand value, it is sobering to realise that this single direct expense already represents 7.7% of the estimated cost for the proposed introduction of vibration OELs.

A related perspective on this number is the direct compensation for occupational injuries and diseases in the SAMI which amounted to 337 million Rand in 2019. This amounts to around 30% of the estimated cost (Sibanye Stillwater Integrated Report, 2019).

This is again a direct compensation payment to employees and does not take any account of administration costs, regulatory costs, etc.

In determining the estimated cost a number of very crude assumptions needed to be applied in the cost model as a result of the complexity identified within each cost category, those being: Exposure monitoring costs, medical validation costs and costs associated with compensation & healthcare. As such, while a financial cost is determined, it only represents a first estimate which best uses presently available information and at least serves as a rational basis for potential future work in this field.

19.1.2  Proposed exposure action values and exposure limit values

In light of the discussion in the previous section it is proposed that the SAMI adopts vibration OELs which distinguish between so-called exposure action values and exposure limit values.

19.1.2.1 Whole-body vibration

19.1.2.1.1 Exposure Action Value (EAV)

If the daily vibration exposure $A(8)$ is likely to exceed 0.5 m/s$^2$ or the vibration dose value ($V_{DV}$) exceeds 9.1 m/s$^{1.75}$, action should be taken to reduce the exposure to below these values.

19.1.2.1.2 Exposure Limit Value (ELV)

Controls must be put in place to ensure workers are not subjected to a daily vibration exposure $A(8)$ of more than 1.15 m/s$^2$ or a vibration dose value ($V_{DV}$) of 21 m/s$^{1.75}$.

19.1.2.2 Hand-Arm vibration

19.1.2.2.1 Exposure Action Value (EAV)

If the daily vibration exposure $A(8)$ is likely to exceed 2.5 m/s$^2$ action should be taken to reduce the exposure to below this value.

19.1.2.2.2 Exposure Limit Value (ELV)

Controls must be put in place to ensure workers are not subjected to a daily vibration exposure $A(8)$ of more than 5.0 m/s$^2$.

19.1.3  Proposed Guidance Note for the Measurement and Assessment of Whole-body Vibration in the South African Mining Industry

A proposed guidance note for the measurement and assessment of whole-body vibration in the South African mining industry was developed and is attached to this report as Appendix 25.2.
19.1.4  Proposed Guidance Note for the Measurement and Assessment of Hand-arm Vibration in the South African Mining Industry

A proposed guidance note for the measurement and assessment of hand-arm vibration in the South African mining industry was developed and is attached to this report as Appendix 25.3.
PART 4 | CONCLUSIONS, RECOMMENDATIONS
20 CONCLUSIONS

20.1 NOISE

20.1.1 Impact of Current Noise OELs on Employees

The conclusions can be summarised as follows:

- The percentage of occupational noise exposed employees that were exposed to noise levels above the first OEL (85dBA_{eq}, 8h) for all commodities increased by 5.1% from 2014 (203 582 employees) to 2018 (213 899 employees).
- No evidence could be obtained that data was recorded or utilised to manage the second OEL (i.e. peak sound level of 135 dB(A)).
- The percentage of employees exposed to noise concentrations above the legislated OEL were 69.3% when compared to the total number of noise exposed employees and 46.9% when compared to the total number of employed employees for 2018.
- The percentage of employed employees compensated for NIHL reduced from 0.226% to 0.100% for the period 2008 to 2018.
- The percentage of employees that are exposed to noise levels above the OEL far exceed those that are compensated for NIHL.
- Working shifts in excess of eight hours per day is frequently experienced.
- Working shifts longer than twelve hours were also recorded at the project gold, coal, chrome and iron-ore mines.
- There is still a number of equipment types utilised by the SAMI that produce noise levels higher than 85dB(A) and some of these still generate noise levels above 104 dB(A).
- The financial model suggests that the total annualised financial cost (based on a number of assumptions) currently associated with noise exposure is R 74 805 796. This total cost is estimated from NIHL lump sum payments (R 50 330 291), replacement costs (R 8 786 104) and other indirect costs (R 15 689 400).
- The most recent national and international noise reduction research is focused on coal mining and also more towards the reduction of noise by means of engineering controls.
- Mine Occupational Hygienists, from the project mines, are generally of the opinion that:
  - It is possible to comply to the current OELs.
  - Preventative maintenance of equipment programmes is lacking in its effectiveness.
  - Employers are making an effort to control noise exposures.
  - Equipment manufacturers and suppliers do not do enough to reduce noise from equipment.
  - Employees do not do enough protect themselves from noisy equipment.
  - There is currently new technology that will assist in the reduction of noise from equipment.
The new technology that is available to reduce noise from equipment is expensive and difficult to implement.

The control of noise is a high management priority at their operations.

- It is a common practice at most mines and in other industries that HPDs must be worn in areas where noise can be present and this requirement is generally well enforced. The use of PPE (HPD’s) is always regarded as a last resort when protecting employees against noise exposure. However, in practice it is most likely that HPDs are generally implemented as a first line of defence against harm caused by exposure to noise. Although not specifically investigated it can be reasonably assumed that this practice is the main reason for the current NIHL compensation rates being much lower than expected, based on the high percentage of employees being exposed to noise levels higher than the OEL of (85dBA, 8h).

- The changing of the noise OELs can potentially have large practical and financial implications for the South African Mining Industry. The information and evidence gathered during earlier parts of the project will be utilised to formulate an informed opinion on the relevance and applicability of the current noise OELs.

### 20.1.2 Relevance and Applicability of the Current OEL as evaluated by industry

Conclusions from the industry workshop can be summarised as follows:

A small majority of the workshop attendees (48.8%) believe that the current personal noise exposure OEL of 85 dB(A) must not be reduced, while 46.3% believed the OEL should be reduced and 4.9% did not have an opinion.

The majority of the workshop attendees (61.1%) believe that the current personal noise exposure OEL must not be revised BUT that more effort must be given to reducing current noise exposures. The research team agree with this statement as the current exposures above the OEL of 85 dB(A) should not be tolerated.

The majority of the workshop attendees (51.7%) believe that the current personal noise Peak Sound Level of 135 dB(A) must be reduced, while 31% believed the Peak Sound Level OEL should not be reduced and 17.3% did not have an opinion. A fast majority of the workshop attendees (71.3%) also believe that the current DMRE Noise Exposure report must be revised to include the reporting of Peak Sound Level. The research team believe that the Peak Sound Level OEL should be revised in legislation to indicate that this is the maximum dB(A) that should not be exceeded at any time during personal sampling programme. The introduction of this parameter into mandatory DMRE reporting mechanisms will enhance understanding and research needs in support of this OEL.

The majority of the workshop attendees (79.5%) believe that the DMRE Exposure Categories for personal noise exposure should be changed as suggested by the research team.

Unfortunately, the opinion of the workshop attendees on the use of shift adjustment methodologies for extended shifts could not be obtained. Th

The majority of the workshop attendees (67.6%) believe that the current noise over-exposure methodology must be enhanced to include the "NIOHS Accumulative % Dose" method. The
research team support the introduction of this accumulated % dose methodology as an additional tool in over-exposure investigations.

The majority of the workshop attendees (93%) believe that a Risk Ranking Method for equipment noise should be implemented for prioritization purposes. The research team suggest that a simplified method be developed and implemented for the SAMI.

71.1% of the workshop attendees think that a risk ranking method for equipment noise should be mandatory and that the method should be specified by the DMRE, 23.7% think that the risk rating method should be mandatory but that the method must be determined by each individual mine and 5.3% think such a method should not be introduced.

It is the opinion of the research team that the current OEL of 85 dB(A) should not be revised. This conclusion is reached as:

- The percentage of employees exposed to noise concentrations above the legislated OEL of 85 dB(A) were 69.3% when compared to the total number of noise exposed employees and 46.9% when compared to the total number of employed employees for 2018;
- The percentage of employed employees compensated for NIHL reduced from 0.226% to 0.100% for the period 2008 to 2018;
- Therefore, a reduction in the OEL would have been justifiable if the compensation rates exceed the over-exposure rates. However, the current data indicate the opposite.

### 20.2 VIBRATION

#### 20.2.1 Impact of Vibration in the SAMI

For vibration there are no existing Occupational Exposure Limits in South Africa. There is therefore also comparatively little data available. This applies to the vibration levels and exposure times. More importantly there is obviously no South African data available on compensation claims.

The data that was available and captured was however analysed to identify general trends in the data that might be of relevance to the potential formulation of South African OELs.

A number of conclusions were reached relating to the data:

- While WBV levels in the SAMI does approach caution levels in some cases, however WBV in the SAMI are generally not excessively high. This is very different for the case of HAV where vibration levels are very high.
- Although lower back pain is recognised by a few European countries as a compensable disease, there is little evidence of successful whole-body vibration compensation claims in the world. This is very different for HAV where there have been very significant claims.
- Neither WBV nor HAV vibration levels are widely reported in the mining industry during normal operations.
- South African WBV and HAV vibration exposures seem to be, if anything, lower or at least comparable to vibration measurements that have been reported at international mining sites.
• It does not seem as if technology has played a significant role in either increasing or decreasing vibration exposure levels over the past two decades. It is unlikely that this will change in the near future, unless the regulatory environment changes.

In addition to the physical impact of vibration on employees, it was also deemed important to determine the financial impact associated with the current vibration exposure in South African mines. The financial model presented represents an approximation of the true cost associated with the current vibration exposure levels. It is noted that while every effort was made to determine the most accurate costing implications, simplifying assumptions had to be made based on the availability of information.

The results of this financial assessment indicate a very substantial increase in the total cost of the mining industry as a result of introducing vibration OELs, with the annual cost to the mining industry estimated to increase by approximately R1.16 billion annually.

20.2.2 Relevance and Applicability of vibration impact as evaluated by industry

In the workshop that was designed to gauge industry perceptions with respect to the importance of vibration in the SAMI and the desirability of vibration OELs, the following was determined:

There was a strong consensus (95%) amongst the workshop participants that there is a need for national OELs for vibration. There was a clear indication (54%) from the workshop participants that South Africa needs a customized SA approach to deal with vibration OELs. While there are sentiments for the European Union approach (EU Directive) (29%) as well as for the ACGIH approach (11%), a time-intensity approach will be required in the SAMI, in order for hand-held rock drill operations to be able to continue.

74% of the respondents believe that A(8) and VDV will suffice as the main parameters to characterize human vibration. It is however clear that there is some concern about the effects of shock and it is suggested that exposure dose also be recorded for WBV operations.

38% of respondents believe that WBV is very important and another 38% believe it is critically important in the SAMI. For HAV 66% consider it very important while 14% consider it critically important. It is clear that WBV and HAV are both considered at least very important by the majority of respondents.

There is an overwhelming indication (100%) from the respondents that rock drill operations are exposing operators to unacceptable levels of vibration.

In terms of the typical exposure times for WBV and HAV there is clearly some uncertainty. For WBV 50% indicate that an 8 h exposure time is typical and 50% disagree. Likewise, for HAV 47% regard 4 h exposure per day as typical, while 53% disagree. 93% of respondents believe that it would be necessary to conduct onsite exposure time studies. The team supports this but believe that this does not have to delay the recommendation on OELs.
21 RECOMMENDATIONS

21.1 NOISE

21.1.1 Impact of Current Noise OELs on Employees

The recommendations can be summarised as follows:

The classification of equipment can be used to group equipment types to enable the implementation of focused noise reduction initiatives, e.g. the controls required to reduce noise from stationary equipment might be similar for most types of stationary equipment (e.g. building a wall around it) but might differ from controls for handheld equipment (e.g. purchasing new generation equipment that produce less noise).

Current data recording systems should be enhanced, or new systems should be developed that would inform and guide national and individual mines noise reduction strategies. Such system/s should enable guidance from measured data sources and not merely follow industry trends. As an example, tyre deflation is being addressed as a leading practice to enable reduction of employees’ noise exposure. However, no data could be obtained from any of the data sources quantifying the noise levels from this activity.

As evidenced throughout the financial model, many of the costing elements required high-level assumptions in order to compute a financial impact. The reason for this is attributable, directly, to the complexity involved in each one of the cost categories identified.

For illustration, consider training costs associated with replacement (arguably the easiest cost to comprehend and extrapolate). In the model a blanket rate of R 10 000 was used for the cost determination, however as identified by Preis and Webber-Youngman (2014), the following cost ‘sub-categories’ were identified: Costs to attract candidates, Costs to select candidates, Costs for interviews, Costs for psychometric assessments, Administrative costs, accounting costs, legal costs, Travel and lodging expenses, Costs for medical examinations, Training costs, etc.

As a result of this, greater accuracy on the financial results contained herein could be provided with further research which focuses, specifically, on elaborating and quantifying the components within the cost-categories identified.

21.1.2 Noise OELs

The recommendations for noise exposure can be summarised as follows:

- The current OEL of 85 dBAeq, 8h should not be revised;
- More effort must be given to reducing current noise exposures;
- The Peak Sound Level OEL of 135 dBAeq, 8h should be revised in legislation to indicate that this is the Maximum Instantaneous Exposure dB(A) that should not be exceeded at any time during the personal sampling programme;
- The introduction of Maximum Instantaneous Exposure into mandatory DMRE reporting mechanisms will enhance understanding and research needs in support of this OEL;
- The DMRE Exposure Categories for personal noise exposure should be revised to categories all exposures above the 85 dBAeq, 8h OEL as A-Category exposures. The current OEL and other Noise Limit Ratings is based on the understanding that employees
are not exposed to these noise levels for more than 8 hours per day or more than 40 hours per week. Although the utilization of \( L_{Aeq,8h} \) caters for corrections to be made based on a specific shift being longer or shorter than 8 hours, corrections are still required for circumstances where the 40 hours per working week is exceeded. Mines should identify and implement appropriate methodology to cater for such corrections.

• As an example, the methodology described in ISO 9612, section 11.4 might be adopted as follows to allow for such corrections to be made;

• The current noise over-exposure methodology must be enhanced to include the "NIOHS Accumulative % Dose" method;

• A simplified risk ranking method for noise producing equipment be developed and implemented for the SAMI. This method must be developed to assist in identifying equipment for priority noise exposure reduction program purposes;

• The format and level of implementation of such a risk ranking method for noise producing equipment must be determined by the inclusive structures of the MHSC.

21.1.3 Proposed Guidance Note for the Measurement and Assessment of Noise in the South African Mining Industry

A proposed guidance note for the measurement and assessment of noise in the South African mining industry was developed and is attached to this report as Appendix 25.1.

21.2 VIBRATION

21.2.1 General Recommendations

The following general recommendations are made with respect to vibration exposure:

• New OELs should be implemented for whole-body vibration and for hand-arm vibration;

• The European Directive 2002/44/EC is the most appropriate international benchmark for new South African vibration OELs;

• Based on this premise it is recommended that the proposed vibration OELs be based on the concept of exposure action values (EAVs) and exposure limit values (EALs);

• A notable and very significant deviation from the European Directive is the EAL for hand-arm vibration. It is proposed that a significantly increased temporary EAL be accepted for hand-arm vibration in the rock drill context, in order for the SAMI to adjust to the new regulated environment;

• More effort is required to reduce current vibration exposures. This should include engineering as well as administrative controls.

• A simplified risk assessment database for vibration transmitting equipment should be developed, implemented and maintained for the SAMI. This database must be developed to assist in identifying equipment for priority vibration exposure reduction programme purposes. It is suggested that as for the case with noise, the responsibility for an equipment based vibration should reside with a body such as the Minerals Council.

• Simple questionnaires must be developed to capture vibration related disorders for WBV and HAV, during the annual medical evaluations.
Rock drills should receive special attention in any vibration control programme.

The format and development of such a risk ranking database for vibration transmitting equipment must be determined by the inclusive structures of the MHSC.

Previous work by the MHSC (as documented in the Appendices of the two proposed vibration guidance notes) should serve as the basis for data which is even more representative of the SAMI.

A fairly sophisticated financial model was developed to take account of the financial implications of introducing a vibration OEL. While the inputs to such a model are obviously very difficult to determine and would require a major research project in its own right, a model was developed and applied based on the best estimated inputs the team could determine. Validation of the estimate is not possible at this stage. A few ‘sanity checks’ were however conducted that suggest that the number is at least plausible and should serve as an input to the MHSC deliberations on the proposed introduction of vibration OELs.

21.2.2 Proposed Exposure Vibration Action Value Exposure Limit Values

It is specifically recommended that the SAMI adopts vibration OELs which distinguish between so-called exposure action values and exposure limit values for whole-body vibration and for hand-arm vibration:

21.2.2.1 Whole-body vibration

21.2.2.1.1 Exposure Action Value (EAV)

If the daily vibration exposure $A(8)$ is likely to exceed 0.5 m/s$^2$ or the vibration dose value ($V_DV$) exceeds 9.1 m/s$^{1.75}$, action should be taken to reduce the exposure to below these values.

21.2.2.1.2 Exposure Limit Value (ELV)

Controls must be put in place to ensure workers are not subjected to a daily vibration exposure $A(8)$ of more than 1.15 m/s$^2$ or a vibration dose value ($V_DV$) of 21 m/s$^{1.75}$.

21.2.2.2 Hand-Arm vibration

21.2.2.2.1 Exposure Action Value (EAV)

If the daily vibration exposure $A(8)$ is likely to exceed 2.5 m/s$^2$ action should be taken to reduce the exposure to below this value.

21.2.2.2.2 Exposure Limit Value (ELV)

Controls must be put in place to ensure workers are not subjected to a daily vibration exposure $A(8)$ of more than 5.0 m/s$^2$.

Immediately instituting the HAV occupational exposure limits adopted elsewhere in the world would however very severely disrupt SAMI operations and a phased approach is therefore proposed, to allow the industry to react to the challenge of reducing vibration exposure levels.

It is recommended that an interim level be set at 13 m/s$^2$ which would subsequently managed down to 5 m/s$^2$ over a 5 year period.
21.2.3 Proposed Guidance Note for the Measurement and Assessment of Whole-body Vibration in the South African Mining Industry

Proposed guidance notes for the measurement and assessment of whole-body vibration and hand-arm vibration in the South African mining industry were developed and are attached to this report as Appendix 25.2 and Appendix 25.3.
22 DISSEMINATION OPPORTUNITIES

It is recommended that the MHSC and associated stakeholders review the guidance notes produced in Appendix 25.1, 25.2 and 25.3 along with the proposed noise and vibration OELs for potential introduction into the SAMI.

This may be the appropriate place to discuss dissemination. Large chunks of the draft report, including many figures, have been removed and replaced with a reference to a Milestone Report. These are usually not circulated to industry.

While I applaud the delivery of short, concise final reports, in this case people in the SAMI must have access not only to the Final Report but also the Milestone 2 to 6 Reports. The MHSC must decide how these are disseminated along with the Final Report, otherwise a lot of the work undertaken will not be available.

The detailed Milestone reports are however separately listed in the list of references so that they could be traced by the serious researcher. These reports are however not cited in the main report, so that the entire document can be read as a coherent document with a coherent set of references.
23 NEXT MILESTONE

None. Project Completed.
24 REFERENCES

ACGIH. TLVs® and BEIs® Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. 2019.


Burns, F.N., 2004, Whole-body and hand-arm vibration: Quantifying the risk of exposure to human vibration at Rossing Uranium Ltd, Namibia, Master's Thesis, Peninsula Technikon, Faculty of Science, Department of Health Sciences, Namibia.


Greenslade, E. and Larsson, T.J., 1997, Reducing vibration exposure from hand-held grinding, sanding and polishing power tools by improvement in equipment and industrial processes, Safety Science, 25(1-3), 143-152.


Hedlund, U., 1989, Raynaud's phenomenon of fingers and toes of miners exposed to local and whole-body vibration and cold. International Archives of Occupational and Environmental Health, 61, 457-461.


CoE 180701 Final Report


SANS 10083. The measurement and assessment of occupational noise for hearing conservation purposes, 2013.


Interim reports:

A number of interim reports were developed during the course of the project. These are not published and publically released and are therefore not cited in this report. The reports do however contain useful related information that might be useful for future researchers in related projects. These reports can be obtained directly from Enterprises University of Pretoria.

Dekker, K., Ker-Fox, J., Oberholster, A., Heyns, S., Claassen, N., Schoeman, J., van der Walt, J., Pullen, M. and Preis, E. MHSC COE 180701 Review the current SAMI noise exposure limit and conduct a study on vibration OEL in relation to the SAMI. Milestone 3 Determine the impact of the current noise OELs on employees' hearing capability, 26 August 2020.


25 APPENDICES

25.1 PROPOSED GUIDANCE NOTE FOR THE MEASUREMENT AND ASSESSMENT OF NOISE IN THE SOUTH AFRICAN MINING INDUSTRY

Please note that the formatting, heading styles, figure number and table numbers in the guidance note differ from the rest of the document. The reason for this is to keep the guidance note as a “standalone” document within this milestone report for reproduction at a later stage.

1. Foreword

1.1 This guidance note has been developed to provide a framework to manage the risk of noise exposure in the South African Mining Industry (SAMI).

1.2 It is aimed towards occupational hygienists and other professionals involved in the assessment and management of noise exposure.

2. Status of guidance note

This guidance note was developed for the mining industry to align the management of noise with best international practice and ensure that the risk of noise exposure is effectively managed to improve occupational health performance in the SAMI.

3. The objective of the guidance note

The guidance note provides a framework for employers at all mines to implement international best practices regarding managing the risk of noise exposure in the SAMI.

4. Definitions and Acronyms

**Competent person** means a person who has acquired the knowledge and skills to carry out a task through training, qualification or experience.

**DMRE** means Department of Minerals and Energy

**Guidance note** means a note issued to assist the SAMI in fulfilling its statuary obligations as outlined in the MHSA.

**HEG** (Homogeneous Exposure Group) means a group of employees whose exposures to noise has been determined to be statistically similar enough that, by monitoring a representative number of individuals in the group, the exposures of the remaining workers can be defined.

**L_{Aeq}** means the A-weighted, equivalent continuous sound level in decibels measured over a stated period of time, **L_{Aeq,T}** where T is the legislated reference time of 8 hours.
Most community and industrial noise measurements are A-weighted, so the $L_{Aeq}$ descriptor is widely used.

$L_{Aeq,8h}$ means the eight-hour equivalent continuous A-weighted sound pressure level. In decibels, it is that steady sound pressure level which would in the course of an 8-hour period deliver the same A-weighted sound energy as that due to the actual noise on any particular representative working day.

**MHSA** means the Mine Health and Safety Act of 1996 (Act no. 29) as amended.

**Noise Rating Limit** means a value of the 8 hour rating level ($L_{Req,8h}$), (85 dBA) at and above which hearing impairment is likely to result.

**OEL** means Occupational Exposure Limit.

**Peak Sound Level** means the greatest instantaneous value of a standard-frequency-weighted sound pressure level, within a stated time interval, and is also known as the peak frequency weighted sound pressure level. If frequency weighting is not specified, the A-frequency weighting is understood to be used.

**SAMI** means the South African Mining Industry.

**Sound Pressure Level** means the pressure level of a sound, measured in decibels (dB). It is equal to $20 \times \log_{10}$ of the ratio of the Route Mean Square (RMS) of sound pressure to the reference of sound pressure (the reference sound pressure in air is $2 \times 10^{-5}$ N/m$^2$, or 0.00002 Pa).

### 5. Occupational Exposure Limit values

5.1 The South African Mining Industry Occupational Exposure Limit for noise is regulated in terms of regulation 22.9(2)(b) of the MHSA. It is regulated as being:

- (1) Noise Exposure: 85 dB $L_{Aeq,8h}$ and
- (2) Peak Sound Level: 135 dB(A).

5.2 The 85 dB$L_{Aeq,8h}$ relates to the maximum noise exposure that an employee might be exposed to for an 8-hour workday and a 40-hour work week.

5.3 This exposure is obtained from full working shift personal exposure monitoring.

5.4 Personal Noise Exposure results is currently reported to the DMRE as being within one of three exposure categories, namely:

a) Category A - $\geq 105$ dB $L_{Aeq,8h}$

b) Category B - $\geq 85$ dB $L_{Aeq,8h}$ to $< 105$ dB $L_{Aeq,8h}$ or

c) Category C - $\geq 82$ dB $L_{Aeq,8h}$ to $< 85$ dB $L_{Aeq,8h}$.

Note: It is proposed that MHSC revise these exposure categories to be: Category A being $\geq 85$ dB $L_{Aeq,8h}$; Category B being $\geq 82$ dB $L_{Aeq,8h}$ to $< 85$ dB $L_{Aeq,8h}$ and Category C being $< 82$ dB $L_{Aeq,8h}$.

5.5 The SAMI must at all times ensure that during reporting of results based on the currently legislated exposure categories, it is made clear that exposures in both the
A and B categories relates to exposures higher than the OEL.

5.6 Although there is currently no requirement to report the Peak Sound Level to the DMRE, records of the Peak Sound Level for recorded personal noise exposure measurements must be kept for investigation and data analysis purposes until such time as the DMRE revise regulation 9.2(7) and report form 21.9(2)(d) to also allow for the Peak Sound Level to be reported to the DMRE.

6. Personal noise over-exposure investigation

6.1 The current methodology introduced by the mines to indicate compliance with the requirements of section 11.5 of the MHS Act must be continued with.

6.2 In addition, a system of “Cumulative Noise Dose” investigation must be implemented; at least one investigation per HEG, preferable the perceived worst-case exposed employee or occupation, to be conducted per quarter.

6.3 The “Cumulative Noise Dose” investigation will consist of:
   a) Task observations (time-motion studies) to be conducted, where employees fitted with personal noise dosimeters are followed and observed during the entire work shift;
   b) All observed tasks, activities and locations are recorded by an observer and start and stop times of tasks or activities are recorded;
   c) Cumulative noise dose plots are generated from the personal noise dosimeter (after shift) and correlated with the observed data;
   d) Periods of high dose accumulation (as indicated by a steep or steeper slope, when compared to the other slopes of the plot) is then used to identify activities that contribute the most to an employee’s noise dose as illustrated by example, in the two graphs below.

6.4 Cumulative Noise Dose investigations must be conducted until such time as a specific corrective action plan (e.g. for an Occupation or a HEG) has been developed and approved by the Mine’s Health and Safety Committee.
6.5 Successful implementation of the Mine Health and Safety Committee’s approved corrective action plan must be followed up with another cumulative noise dose investigation to evaluate the success of the corrective action plan.

7. Noise Source Exposure values

7.1 The SAMI strategies to limit occupational noise exposure and eliminating noise-induced hearing loss in the SAMI were updated from the 2003 milestones, following a summit held by the MHSC during September 2014, as being: By December 2024, the total operational or process noise emitted by any equipment must not exceed a milestone sound pressure level of 107 dB(A).

7.2 The instruction issued by the Chief Inspector of Mines on 4 May 2005 is still relevant and must be complied with. This instruction included the reason for the instruction, measurement criteria, instrument settings to be used, measurement procedures, recording of results procedure, reporting format and reporting frequency.

7.3 The following logarithmic average formula must be used for reporting purposes:

\[
L_{A_{eq}} = 10 \log \left( \frac{\text{anti} \log L_1 + \text{anti} \log L_2 + \text{anti} \log L_3 + \text{anti} \log L_4 + \ldots}{\text{10}} \right)
\]

Where:
- \(L_{A_{eq}}\) is the noise levels measured (\(L_{A_{eq}}\)) in dB(A) for equipment.
- \(n\) is Number of total samples

8. The prioritisation of noise source control measures

8.1 The identification of noise sources must be followed with both a quantitative and qualitative risk assessment. Refer to Chapter 3 of the Handbook of Occupational Health Practices in the South African Mining Industry.

8.2 The prioritization of noise sources for noise mitigation or noise reduction strategies must be based on informed Risk Ratings. This is required to enable the systematic and appropriate reduction of noise from noise sources.

8.3 Risk Rating models used by the mines must be adopted to allow for noise source to be risk rated in terms of:

a) The Sound Pressure level emitted from a noise source, and
b) The number of employees exposed to the noise source, and
c) The duration (time) that employees are exposed to the noise source, and
d) The number of similar noise sources present at the mine.
8.4 Detailed noise source mitigation or noise reduction strategies must be compiled and approved by the Mine Health and Safety Committee for each noise source (or type of noise source) on a mine.

9. **Medical surveillance**

9.1 Medical surveillance must be conducted as stipulated in:

   a) Sections 13(2)(c) and 17 of the MHSA;

   b) The guideline for the compilation of a mandatory code of practice for an occupational health programme for noise (Reference Number: DME 16/3/2/4-A3 of 2003); and

   c) The guideline for the compilation of a mandatory code of practice on the minimum standards of fitness to perform work on mine.

10. **Working Shifts longer than 40 hours per week**

10.1 The current OEL and other Noise Limit Ratings are based on the understanding that employees are not exposed to these noise levels for more than 8 hours per day or more than 40 hours per week. Although the utilization of $L_{Aeq,8h}$ caters for corrections to be made based on a specific shift being longer or shorter than 8 hours, correction is still required for circumstances where the 40 hours per working week is exceeded.

10.2 Mines should identify and implement appropriate methodology to cater for such corrections. As an example, the methodology described in ISO 9612, section 11.4 might be adopted to allow for such corrections to be made.

11. **Subject Matter not discussed in this Guidance Note**

11.1 Refer to the guideline for the compilation of a mandatory code of practice for an occupational health programme for noise (Reference Number: DME 16/3/2/4-A3 of 2003), for any subject matter not discussed in this guidance note.
25.2 PROPOSED GUIDANCE NOTE FOR THE MEASUREMENT AND ASSESSMENT OF WHOLE-BODY VIBRATION IN THE SOUTH AFRICAN MINING INDUSTRY

Please note that the formatting, heading styles, figure number and table numbers in the guidance note differ from the rest of the document. The reason for this is to keep the guidance note as a “standalone” document within this milestone report for reproduction at a later stage.

1. Foreword

1.1 This guidance note has been developed to provide a framework for the management of the risk of whole-body vibration (WBV) exposure in the South African Mining Industry (SAMI).

1.2 It is aimed towards occupational hygienists, ergonomists and other professionals involved in the assessment and management of WBV exposure of humans to vibrating equipment and vehicles.

2. Status of guidance note

This guidance note was developed for the mining industry to align with best international practice, and ensure that the risk of WBV exposure is effectively managed. This is to ensure adherence to the objectives of the MHSA and to improve occupational health performance in the SAMI.

3. The objective of the guidance note

The guidance note provides a framework for employers at all mines to implement best international practice regarding the risk of WBV exposure in the SAMI.

4. Definitions and Acronyms

**Competent person** means a person who has acquired the knowledge and skills to carry out a task through training, qualification or experience.

**Daily vibration exposure** $A(8)$ is the default measure used to assess the WBV exposure of a worker over the course of a working day, normalized to an eight hour reference period, and taking account of the magnitude and duration of vibration.

**Exposure action value (EAV)** is the level of daily vibration exposure $A(8)$ to WBV for a worker above which steps should be taken to minimize exposure.

**Exposure limit value (ELV)** is the level of daily vibration exposure $A(8)$ to WBV for a worker which should not be exceeded.

**Guidance note** means a note issued to assist the SAMI in fulfilling its statutory obligations as outlined in the MHSA.
LHD means load haul dumper.
DMRE means Department of Minerals and Energy.
OEM means original equipment manufacturer.
SAMI means the South African mining industry.

**Vibration dose value (VDV)** is a measure which is preferred when assessing vibration exposure to jolts, shocks and intermittent vibration because it is sensitive to peaks in acceleration levels. Under such circumstances it should be used in addition to the daily vibration exposure A(8).

**WBV** means whole-body vibration.

**Weighted acceleration** is the root mean squared value of a measured vibration signal that has been frequency weighted to account for different human sensitivities to vibration at different frequencies.

**Whole-body vibration (WBV)** is vibration transmitted to the whole-body by the surface supporting it and entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine.

5. **Exposure action values and Exposure limit values**

The South African mining industry identifies EAVs and ELVs consistently with European Directive EU 2002/44/EC Physical Agents Directive, as are outlined below:

5.1 **Exposure Action Value (EAV)**

If the daily vibration exposure \( A(8) \) is likely to exceed 0.5 m/s\(^2\) or the vibration dose value \( VDV \) exceeds 9.1 m/s\(^1.75\), action should be taken to reduce the exposure to below these values.

5.2 **Exposure Limit Value (ELV)**

Controls must be put in place to ensure workers are not subjected to a daily vibration exposure \( A(8) \) of more than 1.15 m/s\(^2\) or a vibration dose value \( VDV \) of 21 m/s\(^1.75\).

6. **Exposure to whole-body vibration**

6.1 **Daily vibration exposure \( A(8) \)**

Exposure to individual sources of constant WBV is calculated from the magnitude of vibration expressed as weighted acceleration in m/s\(^2\) and the actual daily duration of exposure in hours, normalized to an eight hour reference period. The weighted acceleration is calculated by using the appropriate frequency weighting curves for the x, y and z axes as are specified in SANS 2631-1:1997 Mechanical Vibration and Shock-Evaluation of human exposure to whole-body vibration. Part 1: General requirements. These weightings are invariably pre-programmed into the human
vibration meters used for assessing human vibration. 
Alternately it might be implemented in specialist software used with general purpose 
data recorders. This is not discussed in this guidance note.

Exposure to WBV should be calculated using the methods outlined in SANS 2631-1. 
The daily vibration exposure $A(8)$ for a worker exposed to a constant level of WBV for a full day is calculated as:

$$A(8) = a_w \sqrt{\frac{T}{T_0}}$$

where $a_w$ is the weighted vibration magnitude (in m/s²) along the axis which measured highest, after accounting for a weighting factor $k = 1.4$ along the x and y axes. For the vertical z axis the weighting is 1.0.

This is different from hand-arm vibration where $A(8)$ is calculated from the total weighted vibration magnitude along all three orthogonal directions combined.

$T$ is the actual duration (in hours) of exposure to the vibration magnitude $a_w$ and $T_0$ is the reference duration i.e. eight hours.

The weighted vibration magnitude $a_w$ may be determined from previously measured data, information obtained from the original equipment manufacturer (OEM) or from sources like online databases. For compulsory annual medical surveillance these levels must simply be determined from the values that are already reported in Appendix A of this document.

If a worker is exposed to more than one source of WBV during the course of the working day, partial vibration exposures are first calculated from the magnitude and duration for each individual source. The overall $A(8)$ is then calculated from the squares of the partial vibration exposure values, using the equation:

$$A(8) = \sqrt{A_1^2 + A_2^2 + \cdots}$$

where $A_1$, $A_2$, etc. are the partial vibration exposure values for the different vibration sources the worker is exposed to.

$A(8)$ is calculated separately for each of the three axes. The total along the highest axis the worker is exposed is to is then compared to the EAV and ELV. It is recommended that the $A(8)$ calculation be performed with the UK Health & Safety Executive (HSE) WBV calculator:

https://www.hse.gov.uk/vibration/wbv/calculator.htm

6.2 Vibration dose value

Vibration dose value is an alternate measure to report WBV exposure and is generally more suitable to assess exposure to intermittent WBV which includes shocks and jolts. Under these circumstances the vibration dose value ($V_{DV}$) provides a more representative measure than $A(8)$ and should be recorded with the $A(8)$ metric. $V_{DV}$ is a cumulative value, which increases with measurement duration. It is calculated
using the time period of the measurement and the total daily exposure period.

$V_{DV}$ is calculated as the root mean quad of the acceleration. $V_{DV}$ is more sensitive to peaks in the acceleration signal than the $A(8)$ value. As before, weighting factors of 1,4 should be applied along the forward-aft x axis and the lateral y axes. For the vertical z axis the weighting is 1,0. The $V_{DV}$ calculation gives a result in m/s$^{1.75}$.

$V_{DV}$ is not as commonly available as $A(8)$ because of its strong dependence on exposure time. This means that measurements have to be taken to determine the $V_{DV}$ for each type of equipment.

If $V_{DV}$s are available, the daily $V_{DV}$ ($V_{DV_{exp}}$) along each axis can calculated as follows:

$$V_{DV_{exp},x} = 1,4 \times V_{DV_x} \left( \frac{T_{exp}}{T_{meas}} \right)^{0.25}$$

where $V_{DV_x}$ is the reported $V_{DV}$ along the x axis, $T_{exp}$ is the daily duration of exposure to the vibrating equipment, and $T_{meas}$ is the time over which the $V_{DV_x}$ was determined.

An equivalent equation is used along the y axis while the equation for the z axis does not have the 1,4 weighting factor. The highest value of $V_{DV_{exp},x}$, $V_{DV_{exp},y}$ and $V_{DV_{exp},z}$ is the daily $V_{DV}$ to be compared to the EAV and the ELV. If a worker is exposed to more than one source of WBV and the $V_{DS}$s are available, the total $V_{DV}$ along each axis can be calculated as:

$$V_{DV_{exp},x} = (V_{DV_{exp},x1}^4 + V_{DV_{exp},x2}^4 + \ldots)^{0.25}$$

where $V_{DV_{exp},x1}$, $V_{DV_{exp},x2}$, etc. are the partial $V_{DV}$s for each source of vibration along the x axis. The $V_{DV_{exp}}$ which is the highest value along the x, y and z axes is the daily $V_{DV}$ to be compared to the EAV and the ELV. The $V_{DV}$ can be calculated with the same HSE calculator as the $A(8)$ value.

6.3 Uncertainty in assessment of exposure

If either the exposure duration or the vibration magnitude is estimated, for example if exposure duration is based on information obtained from the worker or magnitude of vibration is based on published information obtained from the OEM, the uncertainty may be very high, and reassessment may be required in case workers report vibration related discomfort or lower back pain.

6.4 Measurement axes

For WBV the axis with the highest average root mean square acceleration is used to calculate $A(8)$. Figure 1 shows the standard orientation of the orthogonal x, y, and z axes.
6.5 Original Equipment Manufacturer data and other reported vibration values

OEM data may give a useful indication of the weighted vibration $a_w$ levels to which workers may be exposed. Initial exposure assessments may however need to be verified by measuring vibration magnitudes where WBV exposure depends on external factors such as:

- Vehicle and/or equipment condition.
- Road surface quality.
- Operational speed.
- Local operational procedures.
- Modifications to equipment.
- Maintenance.

An important indicator of whether the EAV may be exceeded is if workers report discomfort or lower back pain.

Appendix A provides WBV $a_w$ values for common equipment in the SAMI.

7. Evaluation of risk

7.1 For all workers that are exposed to occupational WBV, employers must regularly have worker vibration exposure assessed by a competent person, as per section 6 of this guidance note and compared to the EAV and ELV as per section 5. This must be done at least annually as part of the medical surveillance required by the MHSA.

7.2 During medical surveillance it must be determined if a worker suffers from discomfort due to vibration or lower back pain symptoms.

7.3 Once it becomes clear that EAVs are exceeded for more than one worker, all other workers that may be exposed to the same exposures must be subjected to medical surveillance.
7.4 Employers must keep record of the outcomes of 7.1 and 7.2 as per the requirements of the DMRE, from time-to-time.

7.5 An appropriate additional physical investigation must be performed on workers who report having experienced lower back pain symptoms over the past year, to determine fitness for work.

7.6 Employers must identify steps to reduce vibration exposure if vibration EALs are reached.

7.7 Special care should be taken to minimize vibration exposure to pregnant women.

8. **Avoiding or reducing exposure**

8.1 Reporting of uncomfortable WBV or lower back pain shall serve as an indicator of a potential WBV problem which may require controls to be instituted to eliminate or minimize WBV exposure as much as possible.

8.2 Reassessment of WBV may be required if inadequate information about WBV magnitude and duration is available, if the equipment is used differently from before, or if there is uncertainty about the effectiveness of vibration controls. This may include in situ measurement of vibration magnitude and duration.

8.3 Where possible the employer shall establish and implement a control programme to reduce WBV exposure and the associated risks, paying specific attention to:
   - Substitution of other working methods.
   - Equipment selection
   - Purchasing policy.
   - Task and process design.
   - Work schedules.
   - Suspension seats.
   - Maintenance.

8.4 The employer shall ensure that workers who are exposed to risks of WBV shall receive information and training related to the risks of WBV, giving specific attention to:
   - The adverse effects of WBV.
   - Why and how to detect and report signs and symptoms of WBV related injury.
   - Safe working practices related to WBV.
   - EAV and ELV.
   - Measures taken by the employer to eliminate or reduce exposure to WBV.
   - The results of assessment and measurement of WBV conducted in accordance with section 7 of this guidance note.
8.5 If the ELV is exceeded, the employer shall forthwith take action to reduce vibration exposure below the ELV. The employer shall identify and record reasons why the ELV was exceeded and amend the control measures to prevent repetition.

8.6 Where vibration measurements are required, these will be conducted using the procedures outlined in SANS 2631-1:1997.

8.7 Measurement equipment must be fit for purpose. This will typically be a human vibration meter with the appropriate sensors, or a vibration recording system with the appropriate sensors and suitable software to calculate A(8) and preferably VDV.

9. Health surveillance

9.1 Employers shall adopt provisions to ensure appropriate health surveillance of all workers exposed to WBV exceeding the EAV.

9.2 Individual health records must be kept up to date.

9.3 If a worker is found to suffer from an adverse health effect which is considered by a doctor or occupational health care professional to be a result of exposure to WBV at work:

- The worker shall be informed of the results relating to the employee personally and will receive information and advice regarding health surveillance which the employee should undergo.
- The employer shall be informed of significant findings from the health surveillance with due recognition of medical confidentiality.
- The employer shall review its assessment of risks as per section 7 and reduce or avoid exposure as per section 8.
- Consider the possibility of assigning the worker to alternate work where there is little or no risk of further exposure.
- Arrange continued health surveillance of any other worker who has been similarly exposed.
Appendix A: Typical whole-body vibration levels in the South African mining industry

Table A.1 reports typical vibration levels as measured on mining vehicles at South African Mines. Measurements were simultaneously recorded along three orthogonal axes x, y and z.

Table A.1 Typical WBV levels as reported by Van Niekerk, Heyns and Heyns (2000)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>$a_{wx}$</th>
<th>$a_{wy}$</th>
<th>$a_{wz}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulated haul truck (2×)</td>
<td>3,00</td>
<td>1,70</td>
<td>3,40</td>
</tr>
<tr>
<td>Bulldozer (2×)</td>
<td>0.63</td>
<td>0.90</td>
<td>2.00</td>
</tr>
<tr>
<td>Diesel locomotive (1×)</td>
<td>0.06</td>
<td>0.10</td>
<td>0.24</td>
</tr>
<tr>
<td>Drag line operator seat (2×)</td>
<td>0.13</td>
<td>0.13</td>
<td>0.43</td>
</tr>
<tr>
<td>Front end loader (2×)</td>
<td>1.70</td>
<td>5.80</td>
<td>4.20</td>
</tr>
<tr>
<td>Hydraulic face shovel (2×)</td>
<td>1.40</td>
<td>3.00</td>
<td>4.40</td>
</tr>
<tr>
<td>Rigid frame dump truck (1×)</td>
<td>0.34</td>
<td>0.28</td>
<td>0.75</td>
</tr>
<tr>
<td>Rotary crusher (1×)</td>
<td>0.03</td>
<td>0.10</td>
<td>0.42</td>
</tr>
<tr>
<td>Rotary drill seat (1×)</td>
<td>0.07</td>
<td>0.07</td>
<td>0.16</td>
</tr>
<tr>
<td>Rotary drill floor (1×)</td>
<td>0.15</td>
<td>0.18</td>
<td>0.36</td>
</tr>
<tr>
<td>Tractor tipper (1×)</td>
<td>1.70</td>
<td>1.80</td>
<td>3.20</td>
</tr>
<tr>
<td>Vibratory road compactor (1×)</td>
<td>0.30</td>
<td>0.30</td>
<td>0.55</td>
</tr>
<tr>
<td>Vibratory screen walkway (1×)</td>
<td>0.07</td>
<td>0.03</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Table A.2 Typical WBV levels for load haul dumpers (LHDs) reported by Aye and Heyns (2011)

<table>
<thead>
<tr>
<th>LHD</th>
<th>$a_{wx}$</th>
<th>$a_{wy}$</th>
<th>$a_{wz}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volvo A35 LHD</td>
<td>0.61</td>
<td>0.49</td>
<td>0.54</td>
</tr>
<tr>
<td>Mercedes Actros V8 LHD</td>
<td>0.44</td>
<td>0.55</td>
<td>0.65</td>
</tr>
<tr>
<td>Caterpillar 785B</td>
<td>0.50</td>
<td>0.54</td>
<td>0.70</td>
</tr>
<tr>
<td>Tata Novus Truck 3434</td>
<td>0.33</td>
<td>0.43</td>
<td>0.59</td>
</tr>
<tr>
<td>Bell rear Dumper B25D</td>
<td>0.41</td>
<td>0.43</td>
<td>0.38</td>
</tr>
<tr>
<td>Bell rear dumper B40D</td>
<td>0.47</td>
<td>0.81</td>
<td>0.41</td>
</tr>
<tr>
<td>Bell rear dumper B50D</td>
<td>0.32</td>
<td>0.44</td>
<td>0.35</td>
</tr>
<tr>
<td>Iveco truck/trailer (double)</td>
<td>0.54</td>
<td>0.53</td>
<td>0.60</td>
</tr>
<tr>
<td>MAN TGA 33.400 trailer</td>
<td>0.28</td>
<td>0.43</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Table A.3 Typical WBV levels for excavators reported by Van Niekerk, Heyns and Heyns (2000)

<table>
<thead>
<tr>
<th>Excavator</th>
<th>Weighted acceleration levels (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a_{wx}$</td>
</tr>
<tr>
<td>Volvo excavator EC700Blc</td>
<td>0,39</td>
</tr>
<tr>
<td>CAT excavator 320D</td>
<td>0,35</td>
</tr>
<tr>
<td>Hitachi excavator Xavis 370 LCR</td>
<td>0,36</td>
</tr>
<tr>
<td>Hitachi excavator Xavis 500 LCR</td>
<td>0,33</td>
</tr>
<tr>
<td>Hitachi excavator Xavis 670 LCR</td>
<td>0,21</td>
</tr>
<tr>
<td>Hitachi excavator Xavis 670 LCR</td>
<td>0,35</td>
</tr>
<tr>
<td>Komatsu excavator PC1250SP</td>
<td>0,45</td>
</tr>
</tbody>
</table>

Table A.4 Typical WBV levels for other equipment reported by Van Niekerk, Heyns and Heyns (2000)

<table>
<thead>
<tr>
<th>Other Equipment</th>
<th>Weighted acceleration levels (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a_{wx}$</td>
</tr>
<tr>
<td>Bell TLB 315SG</td>
<td>0,35</td>
</tr>
<tr>
<td>Bell water bowser B20C</td>
<td>0,54</td>
</tr>
<tr>
<td>CAT FEL 992G</td>
<td>0,19</td>
</tr>
<tr>
<td>CAT track dozer D9T</td>
<td>0,63</td>
</tr>
<tr>
<td>CAT caterpillar D10R</td>
<td>0,76</td>
</tr>
<tr>
<td>CAT grader 16G</td>
<td>0,42</td>
</tr>
<tr>
<td>CAT 740 diesel bowser</td>
<td>0,61</td>
</tr>
<tr>
<td>Dragline</td>
<td>0,10</td>
</tr>
<tr>
<td>Drilling machine DMM2</td>
<td>0,23</td>
</tr>
<tr>
<td>Kawasaki Safika FEL852 IV</td>
<td>0,38</td>
</tr>
<tr>
<td>Kawasaki FEL</td>
<td>0,34</td>
</tr>
<tr>
<td>Komatsu grader 9D825A</td>
<td>0,33</td>
</tr>
<tr>
<td>Landpac compactor</td>
<td>0,87</td>
</tr>
<tr>
<td>Pit Viper</td>
<td>0,38</td>
</tr>
<tr>
<td>Powerstar 2628 refueller</td>
<td>0,78</td>
</tr>
<tr>
<td>Sany grader</td>
<td>0,19</td>
</tr>
<tr>
<td>Toyota Fortuner</td>
<td>0,56</td>
</tr>
</tbody>
</table>

Van Niekerk, Heyns and Heyns (2000) also tabulate VDV values which are not reproduced here for brevity.
25.3 PROPOSED GUIDANCE NOTE FOR THE MEASUREMENT AND ASSESSMENT OF HAND-ARM VIBRATION IN THE SOUTH AFRICAN MINING INDUSTRY

Please note that the formatting, heading styles, figure number and table numbers in the guidance note differ from the rest of the document. The reason for this is to keep the guidance note as a “standalone” document within this milestone report for reproduction at a later stage.

1. Foreword

1.1 This guidance note has been developed to provide a framework for management of the risk of hand-arm vibration (HAV) exposure in the South African Mining Industry (SAMI).

1.2 It is aimed towards occupational hygienists, ergonomists and other professionals involved in the assessment and management of HAV exposure of humans to hand held and hand-guided vibrating tools and/or equipment.

2. Status of guidance note

This guidance note was developed for the mining industry to align with best international practice, and ensure that the risk of HAV exposure is effectively managed. This is to ensure adherence to the objectives of the MHSA and to improve occupational health performance in the SAMI.

3. The objective of the guidance note

The guidance note provides a framework for employers at all mines to implement best international practice regarding the risk of HAV exposure in the SAMI.

4. Definitions and Acronyms

**Competent person** means a person who has acquired the knowledge and skills to carry out a task through training, qualification or experience.

**Daily vibration exposure** $A(8)$ is the measure used to assess the HAV exposure of a worker over the course of a working day, normalized to an eight hour reference period, and taking account of the magnitude and duration of vibration.

**DMRE** means Department of Minerals and Energy.

**Exposure action value (EAV)** is the level of daily vibration exposure $A(8)$ to HAV for a worker above which steps should be taken to minimize exposure.

**Exposure limit value (ELV)** is the level of daily vibration exposure $A(8)$ to HAV for a worker which should not be exceeded.
Guidance note means a note issued to assist the SAMI in fulfilling its statuary obligations as outlined in the MHSA.

Hand-arm vibration (HAV) is vibration transmitted to a worker's hand and arm when using hand-held or hand-guided tools and/or equipment, and entails risks to the health and safety of workers, in particular with respect to morbidity and trauma of the hand.


OEM means original equipment manufacturer.

SAMI means the South African Mining Industry.

Weighted acceleration is the root mean squared value of a measured vibration signal that has been frequency weighted to account for different human sensitivities to vibration at different frequencies.

5. Exposure action values and Exposure limit values

The South African mining industry identifies an EAV and an ELV consistently with European Directive EU 2002/44/EC Physical Agents Directive, as are outlined below:

5.1 Exposure Action Value (EAV)

If the daily vibration exposure $A(8)$ is likely to exceed $2.5 \text{ m/s}^2$ action should be taken to reduce the exposure to below this value.

5.2 Exposure Limit Value (ELV)

Controls must be put in place to ensure workers are not subjected to a daily vibration exposure $A(8)$ of more than $5.0 \text{ m/s}^2$.

5.3 Temporary Exposure Limit Value for hand-held rock drills

For a period of 5 years after the effective implementation date of this guidance note, the ELV for rock drills will be $13 \text{ m/s}^2$.

6. Exposure to hand-arm vibration

6.1 Daily vibration exposure $A(8)$

Exposure to individual sources of constant HAV is calculated from the magnitude of vibration expressed as weighted acceleration in $\text{m/s}^2$ and the actual daily duration of exposure in hours, normalized to an eight hour reference period. The weighted acceleration is calculated by using the appropriate frequency weighting curves for the x, y and z axes as are specified in ISO 5349-1:2001 Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 1: General requirements. These weightings are invariably pre-programmed into the
human vibration meters used for assessing human vibration. Alternately it might be implemented in specialist software used with general purpose data recorders. This is not discussed in this guidance note.

Exposure to HAV should be calculated using the methods outlined in ISO 5349-1. The daily vibration exposure $A(8)$ for a worker exposed to a constant level of HAV for a full day is calculated as:

$$A(8) = a_{hv} \sqrt{\frac{T}{T_0}}$$

where $a_{hv}$ is the total weighted vibration magnitude (in m/s²). This is different from whole-body vibration where $A(8)$ is calculated separately for each of the three orthogonal axes.

If the $x$, $y$ and $z$ values are reported separately they should be combined as the root-sum-of-squares of the weighted accelerations along the three orthogonal axes $x$, $y$ and $z$.

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2}$$

The $a_{hv}$ value must be assessed at the point where the vibration enters the hand. $T$ is the actual trigger time (in hours) of exposure to the three vibration magnitudes $a_{hv}$ and $T_0$ is the reference duration of eight hours.

The weighted vibration magnitudes $a_{hv}$ may be determined from previously measured data, information obtained from the OEM or from sources like online databases. For compulsory annual medical surveillance these levels must simply be determined from the values that are already reported in Appendix A of this guidance note.

If a worker is exposed to more than one source of HAV during the course of the working day, partial vibration exposures are first calculated from the magnitude and duration for each individual source.

The overall $A(8)$ is then calculated from the squares of the partial vibration exposure values, using the equation:

$$A(8) = \sqrt{A_1^2 + A_2^2 + \cdots}$$

where $A_1$, $A_2$, etc. are the partial vibration exposure values for the different vibration sources the worker is exposed to.

It is recommended that the $A(8)$ calculation be conducted using the UK Health & Safety Executive (HSE) HAV calculator.

https://www.hse.gov.uk/vibration/hav/calculator.htm

6.2 Uncertainty in assessment of exposure

If either the exposure duration or the vibration magnitude is estimated, for example if exposure duration is based on information obtained from the worker or magnitude of vibration is based on published information obtained from the OEM, the uncertainty
may be very high, and reassessment may be required in case workers report vibration related hand-arm disorders.

6.3 Measurement axes

For HAV the root-sum-of-squares of the weighted accelerations along the three orthogonal axes x, y and z as shown in Figure 1, is used to calculate A(8).

![Figure 1 Measurement axes for hand-arm vibration (reproduced from Safe Work Australia)](image)

6.4 Original Equipment Manufacturer data and other reported vibration values

OEM data may give a useful indication of the weighted vibration $a_{hw}$ levels to which workers may be exposed. Initial exposure assessments may however need to be verified by measuring vibration magnitudes where HAV exposure depends on external factors like:

- Tool and/or equipment condition.
- Tool-material interaction (e.g. interaction with rock during rock drilling operations).
- Operational speed.
- Local operational procedures.
- Modifications to tools and/or equipment.
- Maintenance.

Important indicators of whether the EAV may be exceeded is if workers report disturbances of the blood flow to fingers, neurological or locomotor functions of the hand. Appendix A provides HAV $a_{hw}$ values for common equipment in the SAMI.

7. Evaluation of risk

7.1 For all workers that are exposed to occupational HAV, employers must regularly have worker vibration exposure assessed by a competent person, as per section 6 of this guidance note and compared to the EAV and ELV as per section 5. This must be done at least annually as part of the medical surveillance required by the MHSA.

7.2 During medical surveillance it must be determined if a worker suffers from discomfort
due to vibration or HAV symptoms.

7.3 Once it becomes clear that EAVs are exceeded for more than one worker, all other workers that may be exposed to the same exposures must be subjected to medical surveillance.

7.4 Employers must keep record of the outcomes of 7.1 and 7.2 as per the requirements of the DMRE, from time-to-time.

7.5 An appropriate additional physical investigation must be performed on workers who report having experienced HAV over the past year, to determine fitness for work.

7.6 Employers must identify steps to reduce vibration exposure if vibration EALs are reached.

7.7 Special care should be taken to minimize vibration exposure to pregnant women.

8. Avoiding or reducing exposure

8.1 Reporting of uncomfortable HAV or disturbances of the blood flow to fingers, neurological or locomotor functions of the hand, shall serve as an indicator of a potential HAV problem which may require controls to be instituted to eliminate or minimize HAV exposure as much as possible.

8.2 Reassessment of HAV may be required if inadequate information about HAV magnitude and duration is available, if the equipment is used differently from before, or if there is uncertainty about the effectiveness of vibration controls. This may include in situ measurement of vibration magnitude and duration.

8.3 Where possible the employer shall establish and implement a control programme to reduce HAV exposure and the associated risks, paying specific attention to:

- Substitution of other working methods.
- Equipment selection.
- Purchasing policy.
- Workstation design (including anti-vibration handles).
- Work schedules.
- Clothing and personal protection
- Maintenance.

8.4 The employer shall ensure that workers who are exposed to risks of HAV shall receive information and training related to the risks of HAV, giving specific attention to:

- The adverse effects of HAV.
- Why and how to detect and report signs and symptoms of HAV related injury.
- Safe working practices related to HAV.
- EAVs and ELVs.
• Measures taken by the employer to eliminate or reduce exposure to HAV.
• The results of assessment and measurement of HAV conducted in accordance with section 7 of this guidance note.
• The circumstances under which workers are entitled to health surveillance.

8.5 If the ELV is exceeded, the employer shall forthwith take action to reduce vibration exposure below the ELV. The employer shall identify and record reasons why the ELV was exceeded and amend the control measures to prevent repetition.

8.6 Where vibration measurements are required, these will be conducted using the procedures outlined in ISO 5349-1:2001.

8.7 Measurement equipment must be fit for purpose. This will typically be a human vibration meter with the appropriate sensors, or a vibration recording system with the appropriate sensors and suitable software to calculate A(8).

9. Health surveillance

9.1 Employers shall adopt provisions to ensure appropriate health surveillance of all workers exposed to HAV exceeding the EAV.

9.2 Individual health records must be kept up to date.

9.3 If a worker is found to suffer from an adverse health effect which is considered by a doctor or occupational health care professional to be a result of exposure to HAV at work:

• The worker shall be informed of the results relating to the employee personally and will receive information and advice regarding health surveillance which the employee should undergo.
• The employer shall be informed of significant findings from the health surveillance with due recognition of medical confidentiality.
• The employer shall review its assessment of risks as per section 7 and reduce or avoid exposure as per section 8.
• Consider the possibility of assigning the worker to alternate work where there is little or no risk of further exposure.
• Arrange continued health surveillance of any other worker who has been similarly exposed.
Appendix A Typical Hand-Arm vibration levels in the South African Mining Industry

Table A.1 reports typical vibration levels as measured for a series of tools and equipment at South African Mines. Please note that these measurements were conducted before 2001 and in accordance with the 1986 version of the ISO 5349-1 standard, that required measurement only along the dominant axis of vibration. Subsequently the standard was changed to require simultaneous measurement along the x, y and z axes and reflects the observation that the vibration characteristics of some power tools are not dominated by a single directional component.

Measurement of vibration along 3 axes could result in a vibration total value of up to 1,7× the magnitude for a single axis. It is recommended that a typical factor of between 1,2× and 1,5× be used to correct values obtained from single axis measurements.

For rock drills it is currently recommended that 1,2× be used because of the primarily longitudinal motion of the rock drill, despite the use of a jackleg. This factor is based on three axes measurements on rock drills reported by Phillips, Heyns and Nelson (2007).

The dominant measurement directions for the measurements recorded in Table A.1 are indicated adjacent to the average weighted acceleration.

Table A.1 Typical HAV levels as reported by Van Niekerk, Heyns and Heyns (2000)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Average maximum weighted acceleration and direction (m/s²)</th>
<th>Standard deviation of the weighted acceleration level (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumatic rock drills (11)*</td>
<td>24.0 (z)</td>
<td>14.0</td>
</tr>
<tr>
<td>Hydraulic rock drills (9)</td>
<td>24.0 (z)</td>
<td>4.1</td>
</tr>
<tr>
<td>Pavement breakers and jackhammers (6)</td>
<td>19.0 (z)</td>
<td>4.4</td>
</tr>
<tr>
<td>Pneumatic grinders (1)</td>
<td>1.3 (x)</td>
<td>-</td>
</tr>
<tr>
<td>Electrical hammer drills (1)</td>
<td>8.8 (y)</td>
<td>-</td>
</tr>
<tr>
<td>Pneumatic wrench (1)</td>
<td>10.0 (y)</td>
<td>-</td>
</tr>
<tr>
<td>Drill sharpening machine (2)</td>
<td>2.5 (x)</td>
<td>-</td>
</tr>
<tr>
<td>Drill recollaring machine (2)</td>
<td>3.7 (y)</td>
<td>-</td>
</tr>
<tr>
<td>Hand-held compactor (2)</td>
<td>10.3 (z)</td>
<td>-</td>
</tr>
</tbody>
</table>

The numbers behind the equipment names represent the number of equipment pieces that were measured.