FINAL REPORT

PROGRAMME	Longevity of Current Mines (LoCM)	**WORK PACKAGE**	LoCM20WP1 Isidingo Drill Challenge
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1. EXECUTIVE SUMMARY

The South African Mining, Extraction, Research, Development and Innovation (SAMERDI) strategy has been adopted as an initiative to retain the sustainability, profitability and improved safety performance of the mining industry, through the Mining Phakisa outcomes. The Isidingo Drill Challenge initiative was launched in February 2018. The challenge entailed addressing the traditional drill technology employed in South African gold and platinum group metals (PGM) mines. The aim of the initiative was to improve the efficiency and safety with which drilling occurs while concurrently creating new opportunities for local Original Equipment Manufacturers (OEMs) to operate within the mine value-chain.

Phase III of the Isidingo Drill Challenge involved underground testing of both the HPE and Novatek drill units, as well as the processes and activities undertaken during the Isidingo Drill Challenge were evaluated for compliance in accordance with the guideline for the inclusion of workers in the equipment design and development process Developed by the Successful Application of Technology Centred Around People (SATCAP) Programme.

The underground performance testing was completed over the period of two months. The Novatek drill unit was tested at Impala Platinum Mine 10 shaft, at working place 19/53 3 South Panel. The HPE drill unit was tested at the Impala Platinum Mine 12 shaft, 20-level in section 1233 working place 20UN199. The drill units were tested on the week of 2 August 2021 to 6 August 2021, and a second week, a month later from 20 September to 23 September 2021.

The six primary criteria assessed during underground testing of the drill prototypes were penetration rate, weight, noise, parallelism, power source and assemble and dissemble times. The four secondary criteria that were assessed were water consumption, vibration, safety and post-blast face conditions.

The drill performances were determined using a pre-published weighted matrix and the drill performance outcomes were calculated and rated based on a quantitative score. Both the HPE and Novatek prototype drill units complied with the guideline for the inclusion of workers in the equipment design and development process and were successful in meeting the criteria for the underground Isidingo drill performance as both participants delivered a rock drill unit which drills faster, lighter and safer to use in the South African mining industry. Although both drill units emitted less noise as compared to other drills used in the mining sector, both drills emitted noise levels in excess of the 85 dB(A) criteria. The Isidingo Drill Challenge has succeeded in using research, development and innovation to achieve this feat.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXURES

LIST OF ACRONYMS

EAV	: Exposure Action Value
ELV	: Exposure Limit Value
HAV	: Hand Arm Vibration
HAVS	: Hand Arm Vibration Syndrome
ISO	: International Standards Organisation
LoCM	: Longevity of Current Mines
MHSC	: Mine Health and Safety Council
NIHL	: Noise induced hearing loss
RDO	: Rock drill operator
OEL	: Occupational Exposure Limit
OEM	: Original Equipment Manufacturers
OHS	: Occupational Health and Safety
PGM	: Platinum Group Metals

SAMERDI : The South African Mining, Extraction, Research, Development and Innovation

SATCAP : Successful Application of Technology Centred Around People

SLM : Sound Level Meter

WIM : Women in Mining

2. ACKNOWLEDGEMENTS

The Mandela Mining Precinct would like to acknowledge Impala Platinum Mine management for accommodating the Isidingo Drill Challenge and the research teams on their premises. The support from mine management was crucial in obtaining the on-site data.

Further acknowledgement goes to the challenge participants, namely Novatek and HPE, who showed great drive by agreeing to partake in the Isidingo Drill Challenge. A great deal of dedication and adaptability was required as some of the criteria required the OEMs to forge ahead of the current industry norms. The OEMs rose to the challenge by finding solutions when issues were faced and developed their prototypes within 120 calendar days, a significant achievement all around.

3. BACKGROUND

The SAMERDI strategy was adopted as an initiative to retain the sustainability, profitability and improved safety performance of the mining industry, through the Mining Phakisa outcomes. This will be achieved through improving the competitiveness of the sector and creating new opportunities for South African based companies to operate in areas along the entire value-chain. To increase the mining sector competitiveness and to promote research, development and innovation, the Longevity of Current Mines (LoCM) Programme identified the need for an accurate, lighter, faster, quieter, and easily manoeuvrable drilling system utilising an alternative power source from pneumatic power. This was to be achieved through the Isidingo Drill Challenge. This follows from the drilling process being outlined as one of the biggest constraints in the stoping process, as identified in the gaps and recommendations from year 1 of the LoCM Programme.

The challenge entails addressing the outdated traditional drill technology employed in the South African gold and PGM mines. The aim of the initiative was to improve the efficiency and safety with which drilling occurs and present an alternative power source from pneumatic drilling while concurrently creating new opportunities for local original equipment manufacturers (OEMs) to operate within the mine value-chain.

The challenge comprised of 3 phases, namely:

- Phase I: Concept designs and development;
- Phase II: Proof-of concept and prototype development and surface testing performance; and
- Phase III: Underground testing performance and further product development and improvement.

The testing of the drill units was completed over the course of two mine visits (two weeks), starting on the week of 2 August to 6 August 2021 and concluding on the week of 20 September to 23 September 2021. This report evaluates the Novatek and HPE prototype performance with respect to the primary and secondary criteria.

4. AIM OF RESEARCH PROGRAMME

The Isidingo Drill Challenge was initiated to encourage local OEMs to design, prototype and test a rock drill that would satisfy the underground gold and PGM mines' production and occupational health and safety (OHS) requirements. Current pneumatic rock drilling is one of the main bottlenecks in the production cycle, resulting in low productivity and OHS challenges such as poor ergonomics, excessive vibration and heaviness, close proximity of the operator to the face and emission of high noise levels. The Isidingo Drill Challenge, therefore, sought to use innovation to develop a rock drill that would drill faster, be quieter, lighter and safer to use and would revolutionise the South African mining industry.

From the surface test results, the drill units had a higher penetration rate than pneumatic drills. The noise levels were considerably lower than those emitted by the pneumatic rock drills. A clear improvement, in comparison to pneumatic rock drills, was that both HPE and Novatek drill units weigh almost half the current weight of pneumatic rock drills.

The testing of mining equipment in underground environments was crucial in determining the feasibility of integration into current operations without causing unwanted disruptions and bottlenecks. The mining environment is harsh and presents challenges such as humidity, dust, confinement and uneven surfaces. As much as laboratory and surface tests present data that can be used for better designs, it was also critical to test the equipment under real operating conditions. The benefits of underground tests include the following:

- More accurate comparative results within the mining operations;
- High focus supervision provides a greater chance of success for the trial units and provides positive perceptions of the equipment;
- Manufacturers are able to customise equipment to the real operational environment; and
- Costs related to unreliability of equipment (e.g., breakdown costs) are reduced because of a better understanding of the operational environment during the tests.

5. METHODOLOGY

The underground testing phase commenced after the assessment criteria and risk assessment have been developed. The underground testing was conducted over a period of two weeks. This was done to cater for logistics and disruptions such as process delays, equipment breakdown, or any other unforeseen events. This stage involved the testing of a rock drill from each manufacturer, thus emulating, as close as possible the day-to-day drilling activity of the production cycle. The performance results from this stage highlight the impact of the prototype drill units on production and safety by observing operator considerations and monitoring the after-blast conditions. Upon completion of underground test work, performance results of the rock drills were analysed according to the developed criteria and weighted matrix. The results of the assessment informed the project team of the OEMs success in meeting the requirements of the Isidingo Challenge.

The Novatek drill unit was tested at Impala Platinum Mine10 shaft working place 19/53 3 South Panel. The HPE drill unit was tested at the Impala Platinum Mine 12 shaft, 20-level in section1233 working place 20UN199. The Novatek and HPE Isidingo rock drills were tested on the week of 2 August 2021 to 6 August 2021 and concluded on the week of 20 September 2021 to 23 September 2021.

The six primary criteria assessed during underground testing of the drill prototypes were the penetration rate, weight, noise, parallelism, power source and assemble and dissemble times. The four secondary criteria that were assessed were the water consumption, vibration, safety and post-blast face conditions.

This section gives a brief background on the criteria parameters that were monitored during the underground testing of both Isidingo rock drills. The results from the underground testing were analysed and are presented separately for each OEM in section 5.

5.1. Primary criteria

The monitored criteria were divided into two subsections, namely the primary and secondary criteria, which are elaborated on below.

5.1.1. Power source

In conventional mining, drilling is primarily done with the use of compressed air powered rock drills which is considered the most inefficient power source in conventional underground mining environment (Fraser, 2010). The Isidingo Drill Challenge sought to design and develop a rock drill that would use alternative and more efficient power sources.

5.1.2. Weight

The average weight of a conventional pneumatic rock drill ranges between 28 kg to 32 kg excluding the accompanying accessories such as pipes and pusher leg. Carrying such weight is very laborious and requires a lot of effort to move from one area of the working place to another, thus increasing the physical requirements of the rock drill operator (RDO) and decreasing the time available for drilling. It is for this reason that conventional in-stope drilling is associated with male RDOs. There has been a decline in the interest in the RDO related roles due to high physical demands and associated OHS risks. The weight constraint challenges the latest legislation to incorporate women in mining (WIM). The weight reduction would assist in overcoming of the gender association of the RDO job with males by making it both safer and easier for females to handle the machine. The Isidingo Drill Challenge criteria required the newly designed Isidingo rock drill not to exceed 16 kg. The weighing of the drill was undertaken by utilising an electronic weighing scale with a capacity range of 0kg to 200kg.

5.1.3. Parallelism

To obtain a quality and conformant blast, drilling of parallel holes is a crucial component. The holes should be parallel to one another and be in accordance with the mine standard hole angle (horizontal angle to the face of 90^0). One of the Isidingo Drill Challenge goals was to design and develop a rock drill with a feature that ensures parallelism of the drill holes.

5.1.4. Assembly and disassembly time

Assembly time is the time it takes to assemble the rock drill and get it ready to start drilling once all components are in the panel. The disassembly time is the amount of time required to disassemble all the components of the drill unit once concluding drilling operation. The assembly and disassembly times were included as the primary criteria because once the effective drilling time has been reduced by a faster drilling rock drill, it should not be hindered by the time required to assemble and disassemble the rock drill. The combined assembly and disassembly time required was set at 20 minutes or less.

5.1.5. Penetration rate

To obtain a conformant blast, the penetration rate of the rock drill was identified as a crucial criterion to assess the potential improvement in the performance of the drill units. The design and development of a rock drill that can drill faster than its pneumatic counterpart would increase the likelihood of drilling in a shorter period, thus improving shift efficiency and production. Additionally, an improved penetration rate may give the mine the flexibility and choice of reducing the number of operating rock drills in the panel and increase the number of holes drilled per operator. A conventional rock drill has an average penetration rate 0.25 m/min (Ngobese, 2015). The Isidingo rock drill is required to have a higher penetration rate than its pneumatic counterparts.

5.1.6. Noise

An underground hand-held rock drill is one of the major sources of noise underground, producing noise levels of up to 120 dB(A) (Edwards, et al., 2011; Strauss, et al., 2012; O'Brien, et al., 2006). Noise induced hearing loss (NIHL) is a common side effect of prolonged exposure to noise levels in excess of 85 dB(A) among mine workers, more specifically RDOs. One of the Mine Health and Safety Council Summit noise milestones states that by December 2024, noise emitted by equipment should not exceed 107 dB(A), in an attempt to contribute to the larger goal of zero harm (Martin & Magampa, 2018). However, upon internal discussion with the project team this was found very difficult to achieve and the improved requirement was to get as close to 85 dB(A) as possible without exceeding the upper limit of 107 dB(A). A detailed reporting on the noise emitted by each drill unit can be viewed in Annexure A.

5.2. Secondary Criteria

5.2.1. Vibration

Vibration for the purposes of this document is defined as the mechanical vibrations that are transmitted from the rock drill to the operator's hands while operating the rock drill. The common measurements of vibration are Hand Arm Vibration (HAV) and Exposure Limit Value (ELV) and Exposure Action Value (EAV) (van Dyk and Dekker, 2021). HAV refers to the transmission of vibrations from the rock drill to the operator through hands and arms. Constant exposure to excessive HAV may result in HAV Syndrome (HAVS) which is associated with impaired blood circulation, nerve damage and musculoskeletal damage also known as the 'white-knuckle' syndrome (van Dyk and Dekker, 2021). ELV and EAV are exposure limit values to HAV. EAV is the amount of daily exposures while ELV is the amount of vibrations an employee may be exposed to on a single day and is expressed as a function of an eight-hour shift as A(8) in m/s^2 (van Dyk and Dekker, 2021) The intent of the Isidingo Drill Challenge was to design and develop a rock drill whose vibration levels are within the International Standards Organisation (ISO) limits, i.e., ELV A(8) of no higher than 5 m/s^2 (van Dyk and Dekker, 2021). A detailed reporting on vibration can be found in Annexure A.

5.2.2. Human centred design

This criterion assesses the ease of operation of the equipment by the RDO. To understand the acceptability of the rock drill, informal interviews and observations were conducted. The mining crew was asked questions to get their thoughts on the efficiency and ease of use of the rock drills. Observations focused on comments made, difficulties encountered by the RDOs and attitude towards the rock drills.

5.2.3. *Operator consideration*

The design of the rock drill must ensure that it takes into consideration the safety together with the environmental aspects, directly related to the operator. The main aim is to remove the RDOs from the face area, enabling drilling from a supported area.

5.2.4. Post-blast criteria

The post-blast criterion is intended for the evaluation of the blast. Parameters evaluated are availability of sockets, overbreak, advance per blast and overall face shape. The parameters determined based on observations and measurements.

6. PERFORMANCE RESULTS

6.1. Novatek prototype drill

The initial intent of the underground performance testing was to monitor each rock drill over the course of six blasts using the Novatek Isidingo rock drill (Buffalo Rig). However, only three blasts were achieved from the nine days that the research teams spent on site. The reasons for the lost blast days encountered is elaborated on in the section below.

6.1.1. Reasons for lost blast days

- 2 August 2021 and 3 August 2021: The powerpack and pump that supply power to the rock drill were damaged. Drilling of the panel face was not possible due to repair work that was being conducted on the damaged equipment;
- 20 September 2021: The previous blast had a misfired hole, therefore drilling using the Isidingo drill was not done;
- 21 September 2021: The panel was poorly cleaned by the night shift crew, the morning shift was therefore used for the continuation of cleaning. Poor ventilation was also observed in the panel, which was subsequently corrected. When panel was ready for commencement of the Isidingo drill challenge, the mining crew informed the research team that due to time constraints, there was not enough time to use the Novatek Isidingo rock drill as they were not familiar with its use. As a result, the Novatek Isidingo rock drill was not used and no data was recorded;
- 22 September 2021: The Novatek trainer who was familiar with the Novatek Isidingo rock drill was not underground for the shift. Upon discussion with the mining crew, the research team was told that no one on the mining crew was fully trained in the use of the rock drill; and
- 23 September 2021: The research team could not go underground as an underground fire was detected and rescue operations were underway, consequently no data was recorded.

The performance results of the Novatek rock drill are discussed in the following sub sections below.

6.1.2. Power source

The Buffalo Rig was compliant to the required rock drill power source. As the drill is powered by hydropower.

6.1.3. *Weight*

The recorded weight of the Novatek rock drill is 17.3 kg, which is 1.73 kg higher than the weight prescribed in the criteria for the Isidingo Drill Challenge. It is noteworthy that although the Novatek Isidingo rock drill did not meet the criteria set, its weight is still over 10 kg lower than that of a traditional pneumatic rock drill.

6.1.4. *Parallelism*

The parallelism component of the Isidingo rock drill was qualitatively determined as the function of blast advance efficiency. In a panel with an effective hole length of 1.2m, an advance averaging 0.9 m was achieved. This is equivalent to a 75% blast advance efficiency when compared to a 1.2 m drilled length. This indicates a gain in advance of 0.10 m when compared to the historical three-month average of a 0.80 m advance, supporting the idea that the parallelism of the drilled blast holes is within an acceptable margin to achieve a conformant blast.

6.1.5. *Assemble and disassembly time.*

The assembly and disassembly time for the Buffalo Rig was determined by calculating the average time it took the RDO to assemble and disassemble the rock drill set up. The resulting time was 8.67 minutes which is 11.33 minutes lower than that prescribed requirement in the Isidingo Drill Challenge.

6.1.6. *Penetration rate*

The total drill length (metres) and total penetration time (minutes) were used to determine the penetration rate (m/min). The penetration rate for the Novatek Isidingo rock drill was calculated to be 0.61 m/min. The daily penetration rates for the three days monitored are shown in Figure 1. The best penetration rate achieved was 0.63 m/min and the minimum was 0.54 m/min. Daily penetration rates used to calculate the average penetration have a standard deviation of 0.06 m/min, as illustrated in Figure 1.

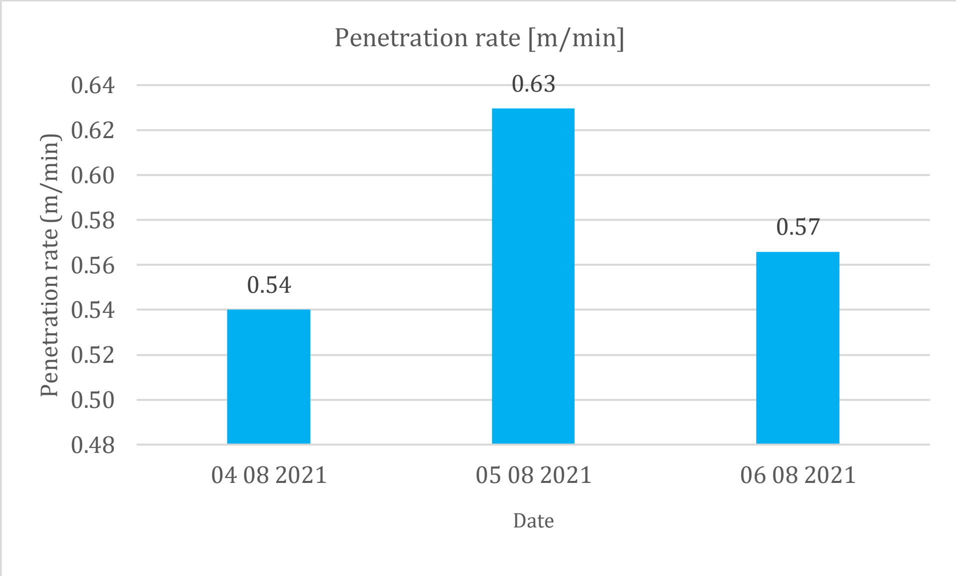

Figure 1: Daily penetration rates

The penetration time of the rock drill was also measured during a surface drilling test at Novatek. Drilling was conducted on a norite block. It took 14 seconds to drill a 0.2 m hole depth which is equivalent to 84 seconds (1.4 minutes) for a 1.2 m hole. Subsequent calculations showed that the rock drill had a penetration rate of 0.86 m/min when drilling norite on surface.

6.1.7. Noise

A set of noise readings were recorded for the Novatek Isidingo rock drill. The measurements were done by an external specialist from KDOHC contracted by the CSIR. However, a panel was unavailable for drilling on the day of noise assessment. Due to this unforeseen circumstance, the sound pressure levels were recorded during drilling of the gully. The gully is considered a confined space which will cause the recorded noise levels to be higher than when panel drilling is practiced. Due to this circumstance, the project team chose to omit these results from the Novatek Isidingo Drill Challenge as they do not represent panel drilling like the measurements recorded for the other participant in the challenge.

6.1.8. Post-blast criteria

Post-blast parameters were not recorded when the research team went underground on the week of 2 August 2021 to 6 August 2021. Post-blast parameters for the Buffalo Rig were not recorded because it was only used to drill a part of the face. Therefore, the condition of the face post-blast could not be conclusively attributed to the Buffalo Rig. No data was recorded in the second mine visit (20 September 2021 to 23 September 2021) because the rock drill was not used at all due to the reasons outlined in section 6.1.1.

6.1.9. Vibration

The Novatek Isidingo rock drill is operated hands-free, as seen in Figure 2, it therefore meets the Isidingo Drill Challenge criteria. The vibration readings recorded are discussed in depth in Annexure A. The vibration readings would be relevant if the rock drill is operated on a pusher leg or on the platform that requires the operator to hold the rock drill while drilling. The ELV for an eight-hour shift should not exceed 5 m/s^2. The vibration readings recorded show that it would take one to five minutes to reach the ELV of 5 m/s^2 if it is held by hand. The vibration readings recorded are therefore presented for additional information purposes only and do not count against the scoring for the Isidingo Drill Challenge.

Figure 2: Novatek Isidingo rock drill in operation

6.1.10. Human centred design

The Isidingo Drill is approximately half the weight of the pneumatic rock drills, weighing 17.3kg. The rock drill also supports hands free drilling and parallelism using the rig frame. The operator considerations make the use of the rock drill easy for the operator, which now enables women to use the equipment. The operators noted the great functionality of the rock drill and the improved drilling speed when compared to its pneumatic counterpart.

6.1.10.1. Operator consideration

The design of the Isidingo rock drill and rig frame combination removes the operator from the face and places them under a supported area. On this basis, the human centred design criterion is achieved, as illustrated in Figure 2.

6.1.11. Summary of Results

Although the data collected was limited, the data was analysed and evaluated against the criteria set for the Isidingo Drill Challenge, the results are presented in Table 1. The following conclusions can be drawn from the analysis and evaluation of results:

- Penetration rate, power source, water consumption, safety as well as assembly and disassembly time met the criteria set in the Isidingo Drill Challenge;
- The weight is 1.73 kg above the set 16 kg in the Isidingo Drill Challenge criteria and over 10 kg lighter than that of a conventional pneumatic rock drill;
- The project team omitted the measured noise results; and
- Drilling with the Novatek Isidingo rock drill is hands-free thereby eliminating the health and safety risks associated with vibration exposure. Vibration readings recorded only serve as additional information to be considered when drilling is hands-on.

Table 1: Summary of Novatek Isidingo rock drill underground testing results

Technical evaluation factor	**Scoring**	**Average measured value**	**Outcome** ☺ Exceed Criteria 😐 Meet Criteria ☹ Shortfall
Primary Criteria			
Power source	The rock drill should not use compressed air as the power source	Hydropower	☺

Weight	The total weight of all the units that will be utilised by the operator during the drilling process should not exceed 16kg	17.3 kg	😐
Parallelism	All drill holes are parallel to the first hole drilled	75% blast advance efficiency	😐
Assembly and disassembly time	The combined assembly and disassembly time should be less than 20 minutes	8.67 min	☺
Penetration rate	The average penetration rate for the Isidingo rock drill should higher than that of the conventional hand-held pneumatic rock drill (0.25 m/min)	0.61 m/min	☺
1. Noise	The drill machine should emit an equivalent noise level of 85 dB(A) or less	Data excluded refer to section 5.1.7	Could not measure
Secondary Criteria			
Human centred design	Design must take the safety together with the environmental aspects, directly related to the operator into consideration	Compliant	☺
Operator considerations	The safety parameters: No operator or assistant to enter face area during set-up and/or drilling	Compliant	☺
Post-blast face conditions	The following post blast conditions: • Face shape • Sockets • Overall face shape • Advance per blast • Overbreak	Compliant	☺
Vibration **	Rock drill vibrations should not result in Exposure Limit Value (ELV) of more than 5.0 m/s^2 in an 8-hour shift	Hands-free drilling	☺

** see comments in section 5.19

6.2. HPE prototype drill

The initial intent was to obtain six blasts drilled with the HPE Isidingo rock drill. The research team was on site for nine days, however, only five days' worth of data was recorded. The reasons for the four days lost blasts were discussed in milestone 3b and 3c reports, they are however summarised below:

6.2.1. Reasons for lost blast days

- 2 August 2021: The panel was not cleaned by the night shift mining crew, therefore, cleaning continued in the morning shift. No drilling of the face was conducted;
- 3 August 2021: There were only four blast holes drilled using the Isidingo rock drill with the hole guide puller for parallelism. Difficulty was encountered whilst putting the hole guide puller in position. Installation of the hole guide puller proved to be time consuming;
- 4 August 2021: The previous production shift was concluded without the completion of drilling due to a pump breakdown. To avoid a possibility of a second lost blast, the mining crew informed the research team that the Isidingo rock drill was not to be tested on the day; and
- 20 September 2021: The research team underwent induction training prior to going underground.

The results from the underground testing of the Isidingo rock drill for each criterion are discussed in the subsections below.

6.2.2. Power source

The Isidingo rock drill was compliant to the required rock drill power source as the Isidingo rock drill is powered by hydropower.

6.2.3. Penetration rate

The total drill length (metres) and total penetration time (minutes) were used to determine the penetration rate (m/min). The average penetration rate was calculated to be 0.65 m/min. The Isidingo drill daily penetration rates are plotted in Figure 3. During the second week of testing, the longest drill time measured was 2.06 min resulting in the lowest penetration rate of 0.57 m/min and the shortest was 1.74 min resulting in the highest penetration rate of 0.70 m/min. The durations recorded during the second week of testing of the Isidingo rock drill show the improvement and familiarity of operators with the drilling system. The standard deviation for the penetration rates over the five days was calculated to be 0.38 m/min, as provided in Figure 3.

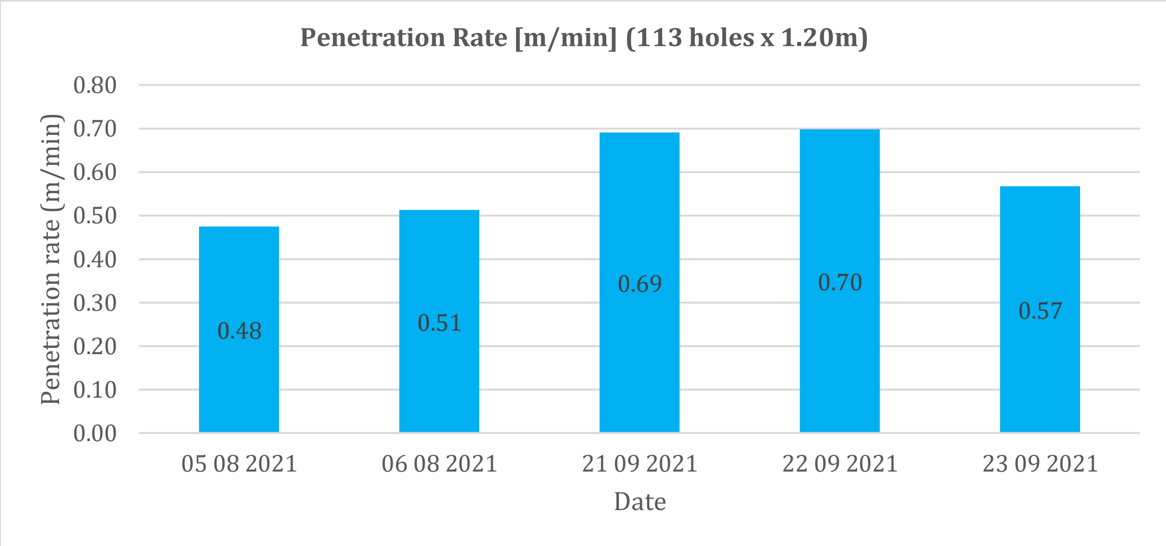

Figure 3: Average penetration rates per day

6.2.4. Weight

The recorded weight of the Isidingo Drill is 15.65 kg, which is 0.35 kg lighter than the weight prescribed in the criteria for the Isidingo Drill Challenge. This is a remarkable achievement which is more than 50% reduction from the pneumatic drills, and the lightest drill unit manufactured in this category.

6.2.5. Parallelism

The parallelism component of the Isidingo rock drill was qualitatively determined as the function of blast advance efficiency. In a panel with an effective hole length 1.2m, an advance averaging 1.08 m was consistently achieved. This is equivalent to a 90% blast advance efficiency to 1.2m length drilled. This indicates a gain in advance of 0.28 m from historical three-month average of 0.80 m, supporting the idea that the parallelism of the drilled blast holes is within an acceptable margin to achieve a conformant blast.

6.2.6. Assemble and disassembly time

The assembly and disassembly time was determined using data recorded over four days. The Isidingo Drill Challenge criteria required that the combined assembly and disassembly time be less than 20 minutes. The average assembly and disassembly time recorded was 9.85 minutes which is compliant to the criteria set for the Isidingo Drill Challenge, these results are shown in Table 2.

Table 2: HPE Isidingo rock drill average combined assemble and disassembly time

Assembly & disassembly time	Value (min)
Day2	9.08
Day 3	8.88
Day 4	10.57
Day 5	10.89
Average assembly & disassembly time	**9.85**

6.2.7. Noise

There were two sets on noise readings that were recorded for the Isidingo rock drill. The initial noise measurements were done by an external specialist from KDOHC contracted by the CSIR. The measurements focused on the noise emitted by the rock drill measured 1 m from the rock drill and 1 m from the face. An average sound pressure level of 105 dB(A) was recorded. The recorded noise level is less than the targeted maximum of 107 dB(A). The second noise readings were recorded by Impala Platinum Mine. The readings were recorded using a noise dosimeter attached close to the operator's ear, using a similar hydro powered rock drill. The recorded results show significantly less noise exposure. The noise readings at an operator ear were recorded to be 90.1 dB(A), see Annexure A.

Noise exposure is improved due to the following reasons:

- The Noise dosimeter readings shows that the 8-hour noise exposure for a hydro powered rock drill is well below the upper exposure limit;
- On average, the drill is further away from the operator's ear, as it moves away from the operator and towards the face;
- The Drill Guide thrusts effectively, in line with an optimal force, which reduces loud "off-collar drilling"; and
- The total drilling time is shorter because the collaring, retracting and penetration times are all faster, thus the duration of time that the operator is exposed to noise is reduced.

6.2.8. Post-blast criteria

No sockets were observed on the face after all the blasts. The overall face stoping width remained at 1.2 m, with a solid and unfractured hanging wall showing no signs of overbreak or backbreak. The advance per blast was 1 m. It can be concluded that the overall face condition and shape after all blasts was as expected, representing a quality blast.

6.2.9. Vibration

The Isidingo rock drill is operated without holding the rock drill, as seen in Figure 4, it therefore meets the Isidingo Drill Challenge criteria. The Isidingo rock drill was used with a hole guide puller for parallelism, which was later realised to have safety, ergonomic and operational efficiency related drawbacks. The hole guide puller was then replaced by a drill guide platform which supports hands-free drilling. The vibration readings for the Isidingo rock drill that were recorded are discussed in depth in Annexure A. The vibration readings would be relevant if the rock drill is operated on a pusher leg or on the platform that requires the operator to hold the rock drill while drilling. The ELV for an eight-hour shift should not exceed 5 m/s^2. The results show that it would take 11 to 29 minutes for the rock drill to reach the ELV of 5 m/s^2 if it is held by hand. The recorded results are therefore presented for additional information purposes only and do not count against the scoring for the Isidingo Drill Challenge.

Figure 4: HPE Isidingo rock drill operating on a drill guide

6.2.10. Human centred design

The HPE Isidingo Drill is approximately half the size of the pneumatic rock drills, weighing 15.65kg. The lightweight rock drill promotes the WIM initiative. The rock drill also supports hands free drilling and parallelism using the Drill Guide. The operators noted the great functionality of the rock drill and the improved drilling speed when compared to its pneumatic counterpart.

6.2.11. *Operator consideration*

The design of the Isidingo Drill and Drill Guide combination removes the operator from the face and places them under a supported area, as illustrated in Figure 4.

A summary of the feedback from the mining crew is given below:

- The rock drill was very light, much lighter than the HPE HHH3 rock drill (which also uses hydropower) they were trialling;
- The Isidingo rock drill was notably faster than the HHH3 and faster than the pneumatic rock drills they had previously used;
- Due to the faster penetration rate of the Isidingo rock drill, drilling of the face is completed in a shorter period. This allows the RDOs to complete their duties faster and thus be able to conclude their shift; and
- The quality of the material used to build the rock drill may not be robust enough for the conventional underground mining environment. Some components are made of plastic or rubber. The RDOs suggested that HPE could consider using a stronger material which still retains the advantage of making the rock drill light.

6.2.12. Summary of Results

The results from underground testing of the Isidingo rock drill are summarised in Table 3. The data collected for each criterion was analysed and evaluated against the original Isidingo Drill Challenge criteria. The following can be concluded:

- The penetration rate, weight, power source, water consumption, safety, and assemble and disassembly time of the Isidingo rock drill meet requirements set in the Isidingo Drill Challenge criteria;
- The noise it emits is higher than the 85 dB(A) set, however, it is lower than the 107 dB(A);
- A 1.08 m advance rate which equates to 90% blast efficiency to the 1.2 m drilled length has been achieved; and
- Drilling with the Isidingo rock drill does not require the operator to hold it thereby eliminating the health and safety risks associated with vibration exposure. Vibration readings recorded only serve as additional information to be considered when drilling is hands-on.

Table 3: Summary of HPE Isidingo rock drill underground testing results

Technical evaluation factor	Scoring	Average measured value	Outcome
			☺ Exceed Criteria 😐 Meet Criteria ☹ Shortfall
Primary Criteria			
Power source	The rock drill should not use compressed air as the power source	Hydropower	☺
Weight	The total weight of all the units that will be utilised by the operator during the drilling process should not exceed 16 kg	15.65 kg	☺
Parallelism	All drill holes are parallel to the first hole drilled.	90% blast advance efficiency	😐
Assemble and disassemble time	The combined assembly and disassembly time should be less than 20 minutes	9.85 min	☺
Penetration rate	The average penetration rate for the Isidingo rock drill should higher than that of the conventional hand-held pneumatic rock drill (0.25 m/min) (Ngobese, 2015)	0.65 m/min	☺
Noise	The drill machine should emit an equivalent noise level of 85 dB(A) or less	105dB(A)	😐
Secondary Criteria			
Human centred design	Design must take the safety together with the environmental aspects, directly related to the operator into consideration.	Compliant	☺
Operator considerations	The safety parameters: No operator or assistant to enter face area during set-up and/or drilling	Compliant	☺
Post-blast face conditions	The following post blast conditions: • Face Shape • Sockets • Overall face shape • Advance per blast • Overbreak	Compliant	☺
Vibration	Rock drill vibrations should not result in Exposure Limit Value (ELV) of more than 5.0 m/s² in an 8-hour shift	Hands-free drilling	☺

** see comments in section 5.2.9

7. EVALUATION PROCESS FOR THE PROTOTYPE ROCK DRILLS

7.1. COMPLIANCE TO THE EQUIPMENT DESIGN GUIDELINE

The Mandela Mining Precinct under the SATCAP programme, undertook a project titled "People-centric modernisation" for the 2020-21 financial year. The project aimed to develop a guideline for the inclusion of stakeholders in the equipment design and development processes. The guideline was developed against the backdrop of the modernising mining sector in South Africa. The aim of the guideline was to promote people-centric modernisation of the South African mining sector. For the purposes of this guideline, a stakeholder is a party that has an interest in a mining company and can either affect or be affected by the business (mining operations). These stakeholders can either be board of directors, all management levels, frontline supervisors, employees (workers), organised labour (unions), contractors, service providers, government (particularly the Department of Mineral Resources and Energy), other mining companies, communities surrounding the mine, non-governmental organisations, local authorities and OEMs.

This section evaluates and compares the process followed and stakeholders involved in the Isidingo Drill Challenge to those suggested in the people-centric guideline for the inclusion of workers in the equipment design and development process. The guideline suggests five main interlinked steps which should be followed in the design and development of equipment are shown in Figure 5 and further elaborated on below:

- **Demand analysis:** The guideline is initiated by various forms of drivers/changes in the environment (i.e. regulatory requirements, best practice developments, production methodology changes, etc.);
- **Product specifications:** This stage focuses on technical specifications that need to align to best practice, regulatory requirements, Safety, Health, Environment and Quality (SHEQ) specifications and other technical requirements around human-centred design;
- **Equipment design and development:** Focused on the development of a technical guideline for users, which is aligned to best practice and the development of a prototype;
- **Demonstration, pilot, review and refinement:** User interaction and ergonomic factors are evaluated in the use of the equipment. Additionally, digital and/or physical interfaces are evaluated during this step;

- **Adoption:** Adoption is evaluated per operation (if economically viable), company, commodity and/or per sector to evaluate the success of adoption. The business case of the product would be used as the basis of basis for this (see step 1).

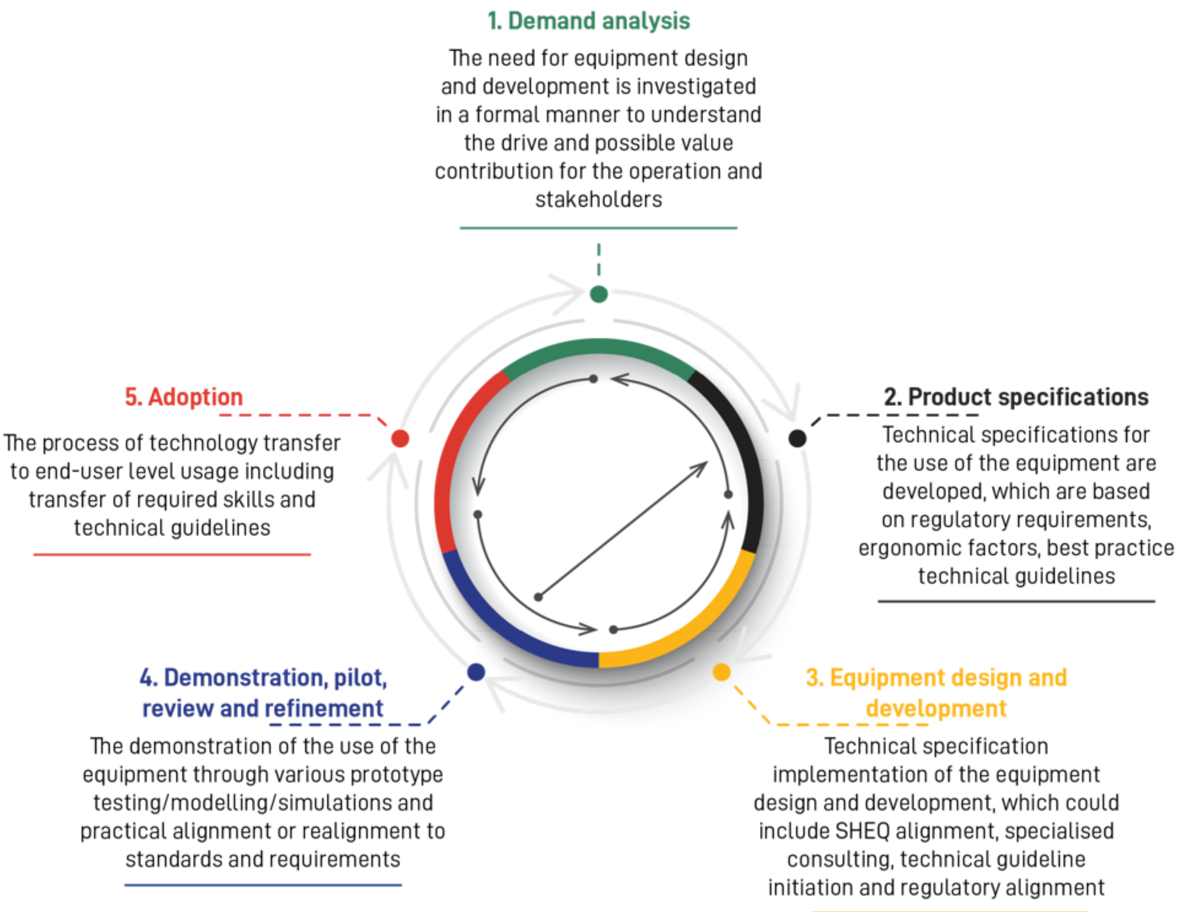

Figure 5: Process flow model for worker inclusion in the equipment design and development process (Pelders, et al., 2021)

The process recommended for the inclusion of workers in the equipment design and development process is outlined in Table 4, Table 5, Table 6 and Table 7 and is compared to the steps followed under the Isidingo Drill Challenge. The guideline suggests five steps, however, only four are discussed in this document because the Isidingo Drill Challenge has gone up to the fourth step so far. The final step of the equipment design and development is yet to commence. However, Annexure B shows the activities and processes associated with the fifth step as recommended by the guideline.

Step 1: Demand analysis

The first step as suggested in the guideline entails identification of the problem or need to start the design and development of the equipment. The development of the Isidingo rock drills is the result of the drilling process being identified as one of the major bottlenecks in the mining cycle due to the inadequate performance of current pneumatic rock drill. The processes and stakeholders involved in the first step are outlined in Table 4.

Table 4: Step 1 - Demand analysis

Step title	**Guideline suggestions**	**Isidingo Drill Challenge process followed**
Description	The need for equipment design and development is investigated in a formal manner to understand the drive and possible value contribution of the operation and stakeholders	• Drilling identified as one of mining cycle bottlenecks, through the LoCM year one research, shift cycle and lost blast analysis.
Process Underpin	• Business case • Context of use definitions (scenarios of use), which include the technical, physical, social, cultural, and organisational environments • Stakeholder identification • SHEQ Analysis • Organisational impact assessment	• Shift cycle activities improvement to obtain daily conformant blast.
Methodology (Examples)	• Brainstorming • Benchmarking best practice • Idea generation methods • Field studies • Surveys • Observations • Technical steering committee establishment and inputs provided • Environmental analysis • Cost-benefit analysis • Role play Context diagram	• Research work and literature reviews • Field work • Interviews • Data analysis
Possible Stakeholder Involved	• Driver: industry / mine management • Lead: OEMs • Mine technical services (e.g. engineering, safety, production)	• Mining researchers • LoCM steering committee • OEMs • Mining industry Stakeholders

	• Support services at mines (e.g. ICT, training, HR, OHS, finance, procurement, legal) • External consultants (e.g. SHEQ, technical designer, programmers) • Indirect input from the workforce from all job grades (e.g., operators, artisans, supervisors, miners, shift bosses) • Labour representatives (if relevant) • Regulator (if relevant) Etc.	
Underpinning Factors	Loop Learning (single, double and triple loop), including hazard analysis Change Management (monitoring and evaluation – communication strategies)	Effective change management principles to be followed

Step 2: Product specification

The Mandela Mining Precinct through the LoCM programme asked the mines what were the most aspects of rock drills that needed improving. The design Isidingo Drill Challenge design criteria was the outcome of the inputs from the mines. Process activities undertaken and stakeholders involved in design specifications are outlined in Table 5.

Table 5: Step 2 - Product specification

Step title	**Guideline suggestions**	**Isidingo Drill Challenge process followed**
Description	Technical specifications for the use of the equipment are developed, based on regulatory requirements, ergonomic factors, best practice technical guidelines	• Decision to develop an improved rock drill; • Rock drill primary and secondary criteria identified for the inclusion in the prototype design.
Process Underpin	• Technical specification determination • Regulatory analysis • Environmental analysis • Ergonomic factor analysis • Best practice benchmarking	• Technical specifications identified were penetration rate, weight, noise, parallelism, assembly and disassembly time, power source, water consumption, vibration, safety (operator consideration) and post-blast conditions
Methodology (Examples)	• Benchmarking • OEM specification	• Collaboration with mining industry representatives

	• Regulatory specifications • Ergonomic guidelines • Focus group discussions • Surveys • Desktop study	• Research and review of literature
Possible Stakeholder Involved	• Industry / mine management, including technical and support services • OEMs • External consultants • Suppliers (if relevant) • Labour representatives • Workforce • Regulator (if relevant)	• Mining industry • Researchers

Step 3: Equipment design and development

Step 3 highlights the process followed and stakeholders involved in the design and develop the rock drill after the required product was specified, as seen in Table 6. Activities undertaken included advertising of the design challenge, submission of proposals and concept designs, selection of qualifying concept designs, and development of prototypes.

Table 6: Step 3 - Equipment design and development

Description	Guideline suggestions	Isidingo Drill Challenge process followed
Description	Technical specification implementation of the equipment design and development, which could include SHEQ alignment, specialised consulting, technical guideline initiation and regulatory alignment	• Isidingo Drill Challenge advertised in public domain. • Rock drill design criteria advertised to the public.
Process Underpin	• Concept development • Technical specification analysis • SHEQ requirement inclusion • Specialised technical development and inputs • Projections and modelling	• Concept designs developed by individuals and organisations with potential to design and develop • Development pf prototypes
Methodology (Examples)	• Organisational prototyping • Design guidelines and standards • Virtual reality (VR) design and projections	• Open design challenge according to specifications provided by the Mandela Mining Precinct

	• Lead user analysis National/international modelling	• Manufacturers followed their in-house design and development processes
Possible Stakeholder Involved	• OEMs • Industry / mine management, including technical and support services • External consultants (if relevant) • Suppliers • Labour representatives • Workforce (direct participation) • Regulator (if relevant) Etc.	• Public media • OEMs • Mining houses • Public with potential to design and develop

Step 4: Demonstration, pilot, review and refinement

Step 4 focuses on the demonstration of the developed prototype. The initial demonstration to various industry stakeholders was done at the Mandela Mining Precinct. The demonstration included the drilling of granite blocks and surface testing of design criteria. The second demonstration process was the underground testing of Isidingo rock drill prototypes. The stakeholders involved included mine management, mine workers, organised labour, researchers and consultants, see Table 7.

Table 7: Step 4 - Demonstration, pilot, review and refinement

Description	Guideline suggestions	Isidingo Drill Challenge process followed
Description	The demonstration of the use of the equipment through various prototype testing/modelling/simulations and practical alignment or realignment to standards and requirements	• Demonstration and testing of prototypes
Process Underpin	• Prototyping and organisation practical testing (mock-up trials) • User testing, feedback and alignment (if required) • Further technical guideline development • Verification and validation	• Demonstration day with various industry stakeholders present • Comments, suggestions, and questions by stakeholders • Surface and underground testing results in the form of reports • Inputs from the underground mine workers
Methodology (Examples)	• Model run • Broader simulations	• CSIR researchers visit to OEM sites • Surface testing of rock drill at the Mandela Mining Precinct

	• Projections (scenario, production, financial, other) • Physical demonstration (prototype concept and site/mock-up demonstration) VR and simulations	• Underground testing of rock drills at Impala Platinum shafts
Possible Stakeholder Involved	• OEMs • Industry / mine management, including technical and support services • External consultants (if relevant) • Suppliers (if relevant) • Labour representatives • Workforce (direct participation) • Regulator • Communities Etc.	Surface testing: • OEMs • Organised labour • Researchers • SETA • Mining personnel • Academia • Government/regulatory • Mining houses • Consultants Underground testing: • OEMs • Mine personnel (Impala Platinum management) • Mine workers (Miner, team leader, and RDOs) • Researchers • Consultants – ETA and KDOHC • Organised labour
Underpinning Factors	Loop Learning (single, double and triple loop), including hazard analysis Change Management (monitoring and evaluation – communication strategies)	• Change of drilling platform from rope guide puller to drill guide by HPE after underground testing

The comparison of processes and activities associated with each step of the guideline to those followed under the Isidingo Drill Challenge shows that Isidingo Drill Challenge complied with the people-centric design and development process outlined in the guideline recommendations.

7.2. COMBINED SUMMARY RESULTS

Table 8 shows the summary of the underground testing of both Isidingo rock drills.

Table 8: Summary of Isidingo drill performance for Novatek and HPE

Evaluation Criteria	Units	Local OEMs		Cut-off	Comments
		Novatek	HPE		
Power source		Hydropower	Hydropower	Non pneumatic	Both OEMs compliant
Weight	kg	17.3	15.65	16	Novatek exceeded by 1.73 kg. HPE within criteria
Parallelism	% Blast Efficiency	75%	90%	80%	Both OEMs above criteria
Assembly and disassembly time	min	8.67	9.85	20	Both OEMs compliant
Penetration rate	m/min	0.61	0.65	0.25	Both within criteria
Noise	dB(A)	110.80	105	85	Novatek data excluded refer to section 5.1.7. HPE drill above 85 dB(A) but below the 107 threshold.
Human centred design		Compliant	Compliant	Compliant	Both OEMs compliant
Operator considerations		Compliant	Compliant	Compliant	Both OEMs compliant
Post-blast face conditions		Compliant	Compliant	Compliant	No data for Novatek. HPE compliant
Vibration **	m/s^2	Hands-free drilling	Hands-free drilling	Compliant	Hands free use. Both OEMs compliant

** see sections 5.1.9 and 5.2.9

Both the HPE and Novatek prototype drill units complied with the guideline for the inclusion of workers in the equipment design and development process and were successful in meeting the criteria for the underground Isidingo drill performance as both participants delivered a rock drill unit which drills faster, lighter and safer to use in the South African mining industry. Although reduces noise level at operator position whilst drilling, there is room for improvement with regards to the noise emitted by the drill units as both emitted noise levels in excess of the 85 db(A) criteria. The Isidingo Challenge has succeeded in using research, development and innovation to achieve this feat.

8. CONCLUSION

The Isidingo Drill Challenge proved to be successful as most of the results were compliant or close to the required criteria, but a significant improvement compared to the pneumatic drills.

Apart from the criteria set by industry been met, there were further key achievements to be noted, which are:

- The development of a rock drill which uses an alternative power source to pneumatic power;
- The development of a rock drill which is approximately 50% lighter than its pneumatic counterpart, this reduces the fatigue gained when handling the rock drill, which now enables woman to use the drill equipment;
- A mini hydropower station was built which replaced compressed air for drilling blast holes, support holes and rig holes, providing high pressure drilling. This infrastructure also allows for hydro powered jet cleaning;
- A safer working environment was provided for the rock drill operator as the Isidingo Drill can be operated under a permanently supported area;
- Reduced drilling time was achieved. This allows for more frequent blasting with the option of at least 50% less operators per panel. The reduction in personnel per panel allows for the utilisation of additional panels in order to increase production outcomes.
- Increased manoeuvrability of the rock drill in narrow reef mining environments allowing for faster movement, safer and more ergonomic operation.

The water consumption was an add-on measure following the trial work conducted at Impala Platinum Mine. The effective measure of water consumed by support and gully drilling equipment was not possible at the time of data recording.

9. RECOMMENDATIONS

The research team is aware that the tests conducted might not have been sufficient to provide conclusive results about the drills. The results are indicative, i.e., indicating the potential of the drills. Thus, there is still a need to conduct extensive underground tests to enable generalisation of the results.

The Isidingo drills provide an alternative power source to pneumatic power. The hydropower system uses a mini-hydropower station which provides a solution to improve drill time. In addition, it reduces safety risk at the face whilst drilling, reduces costs and provide improved production outcome. These rock drills are lighter which accommodates women to operate them.

It is strongly recommended that mining companies who are dependent on pneumatic drills but experience low efficiencies due to ineffective compressed air utilisation to switch to the hydropower Isidingo solutions.

The manufacturers can provide the combined water consumption of the full equipment usage, which includes the various drills used and water jetting applied during the six-month trial conducted at Impala Platinum Mine, which could not be presented as part of the Isidingo Drill Challenge.

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11.ANNEXURES

Annexure A: Noise and vibrations measurement report

KDOHC

REPORT NUMBER: 2021/1000768201

ISIDINGO PROJECT

NOISE AND HAND-ARM VIBRATION ASSESSMENT REPORT

FOR ROCK DRILL TRIAL AT IMPALA PLATINUM

ON BEHALF OF THE CSIR

INTRODUCTION

Surveyors

Tania van Dyk conducted the vibration assessment studies at Impala Platinum. Tania is in possession of a Certificate in Mine Environmental Control and a Master of Science Degree, obtained from the Northwest University.

Kobus (JJ) Dekker conducted the noise assessment studies at Impala Platinum. Kobus is in possession of a Certificate in Mine Environmental Control and a Master in Public Health (Occupational Hygiene) from WITS.

Scope of work

The purpose of this study is to determine the Noise and Hand-arm Vibration (HAV) levels of two types of rock drills that is currently on trial. The following rock drills were evaluated:

- HPE trial rock drill
- Novatek trial rock drill (Isidingo)

KDOHC's responsibilities include the quantification of noise and hand-arm vibration levels for the mentioned rock drills at the Impala Platinum's 12 and 10 shafts.

Background to Project

The CSIR, requested KDOHC to conduct the noise and vibration evaluations according to the above-mentioned scope of work.

HAZARD BACKGROUND INFORMATION

Background Information on Noise

Hazardous noise can destroy the ability to hear clearly and can also make it more difficult to hear sounds necessary for working safely, such as instructions or warning signals. Managing the risks related to noise will assist in:

- protecting workers from hearing loss and disabling tinnitus (ringing in the ears or head)
- improving the conditions for communication and hearing warning sounds
- creating a less stressful and more productive work environment

Hazardous noise affects the functioning of the inner ear, which may cause temporary hearing loss. After a period away from noise, hearing may be restored. With further exposure to hazardous noise, the ear will gradually lose its ability to recover, and the hearing loss will become permanent. Permanent hearing loss can also occur suddenly if a person is exposed to very loud impact or explosive sounds. This type of damage is known as acoustic trauma. Permanent hearing loss results from the destruction of hair cells in the inner ear.

Noise is an unwanted or damaging sound that may damage your hearing and cause other health effects such as stress, hypersensitivity to noise, increased blood pressure and increased heart rate. It can also interfere with communication at work, which could lead to accidents. The normal range of hearing for a healthy young person is from approximately 20 Hz (Hertz) to 20,000 Hz (20 kHz). Our ears are more sensitive to the middle frequencies, which range from 500 Hz to 4000 Hz - the speech frequencies. Hertz is a measure of the pitch or frequency of sound, sometimes referred to as cycles per second.

Noise-induced hearing loss is one of the most common occupational injuries, resulting in health problems for many workers and it presents a significant social and economic cost and in addition, if your hearing is damaged it could cause a workplace accident. The first sign of noise-induced hearing loss is often the difficulty to hear high-pitched sounds.

Noise-induced hearing loss occurs gradually over a long period of time and unfortunately, hearing loss is permanent. Permanent hearing damage that is either caused immediately through a sudden extremely loud noise or gradually due to prolonged exposure to unacceptable noise levels is incurable. Tinnitus, which is a ringing, whistling, buzzing or humming in the ear, is another possible problem arising from excessive exposure to noise. This distressing condition can also lead to disturbed sleep and can reduce a person's enjoyment of life. While there is no cure, some people who suffer from tinnitus may be assisted by undertaking tinnitus retraining therapy, which offers a way to manage the condition.

The harmful effects of noise exposures add up, so you need to watch your noise exposure outside the workplace as well. You should wear hearing protectors if you are doing any noisy work at home such as using power tools. Even if you are exposed to excessive noise for short periods of time it is important to protect your hearing.

Background to Hand-arm vibration

Human vibration is defined as the effect of mechanical vibration on the human body, which can be painful and/or harmful and are in most instances unpleasant. The harmfulness of vibrations mainly depends on the intensity, frequency, and exposure time. There are two types of human vibration:

- Whole-body vibration
- Hand-arm vibration

Hand Arm Vibration (HAV) involves the use of vibrating hand-held power tools, such as rock drills, and is transmitted to the hands and arms when operating these tools. Regular exposure to HAV can cause HAVS which include symptoms such as impaired blood circulation, nerve damage and musculoskeletal damage, and is mainly associated with cold environmental conditions. If left untreated, white finger syndrome can become progressively worse and irreversible damage can occur.

- Symptoms of HAVS
  - Whitening (blanching) of fingers
  - Tingling and loss of sensation in the fingers
  - Loss of light touch
  - Loss of grip strength
- Influencing factors of HAVS
  - Cold, wet conditions
  - Exposure time and frequency of occurrence
  - State of tool maintenance

- Level of insulation on tools
- Grip forces applied
- Hardness of material
- Posture of the arm and hand during tool operation
- Individual operator's skill and technique
- Individual's susceptibility to vibration and personal habits like smoking, drugs etc. (Nicotine is a vasoconstrictor)
- Individual's medical history

Research evaluated the effect of over-exposure to human vibration and results were applied in establishing international standards by the International Standards Organisation (ISO). The ISO define daily vibration exposures in terms of an exposure action value (EAV) and an exposure limit value (ELV). The EAV is the amount of daily exposure to vibration above which you are required to take action to reduce risk and the ELV is the maximum amount of vibration an employee may be exposed to on any single day and are expressed in terms of the Daily vibration exposure, A (8). The daily vibration, A (8) requires an exposure time and is the continuous equivalent acceleration, normalised to 8 hours. It is an 8-hour equivalent vibration total value (3 measured axes of vibration) expressed as the sum of the acceleration values. The A (8) is based on the root-mean-square averaging of the acceleration signal and is measured in m/s^2.

MEASUREMENT METHODOLOGY

Equipment Noise Assessment Methodology

The noise emitted from the trail rock drills were assessed as per the methodology described by the Minerals Council of South Africa (then known as the Chamber of Mines of South Africa) Guidance Note for Noise Measurement of Equipment to ensure compliance with MHSC milestones. A copy of the guidance note is attached as Appendix A.

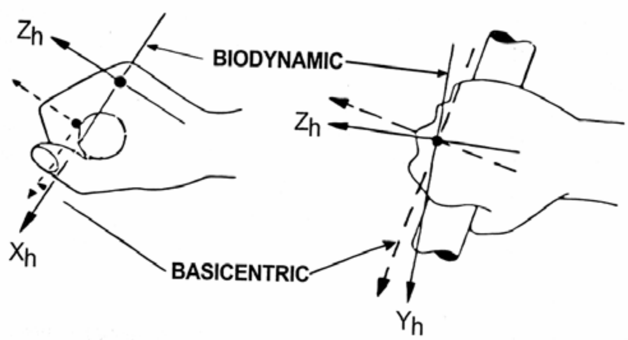
A Casella CEL-63X Type 1 Sound Levels Meter, with the following detail, was utilized to conduct the noise exposure assessments:

- Serial Number: 3921085; 001633; 2103
- Calibration Date: 22 July 2021
- Calibration Due Date: 22 July 2022.

Hand-Arm Vibration Assessment Methodology

HAV measurements were conducted in accordance with ISO Standards. For HAV reference is made to ISO 5349. HAV was measured by placing an accelerometer between the hand of the operator and the equipment measured, as per ISO Standard - ISO 5349-2. An accelerometer is used to measure the vibration from a power tool that is converted to an electrical output, this output is modified to account for the range of frequencies that can cause harm to the hand and arm, which is a frequency weighted value that is measured in m/s^2.

Hand-transmitted vibration is measured at the contact point between the hand and the tool, and are taken in three axes (x, y and z) and the alignment of these axes of the accelerometer should be precise (as illustrated in the picture below).



To keep the accelerometer steady and the 3 measured axes of vibration precise, the accelerometer were tied to the handle of the rock drill during the measurements. HAV levels was measured for the period it takes to complete the drilling of one hole. A total of at least 3 to 5 "Tests" were recorded (measurement of drilling a single hole for each of the rock drills). The time spend to drill a single hole took approximately one minute for both of the trial rock drills.

The Casella Cell Human Vibration Meter, with the following detail, was used to conduct all vibration measurements:

- Serial Number: 20114, 20104, 2008
- Calibration Date: 4-7 December 2020
- Calibration Due Date: December 2021

Measurement Position for HPE Rock Drill (Isidingo Challenge)

The Sound Level Meter (SLM) were positioned 1 meter away from the rock drill and 1 meter away from the face. The SLM were placed 0,6 meter from the footwall as the stoping width (SW) were measured as being 1,2 meters. Also see figure 3.1.

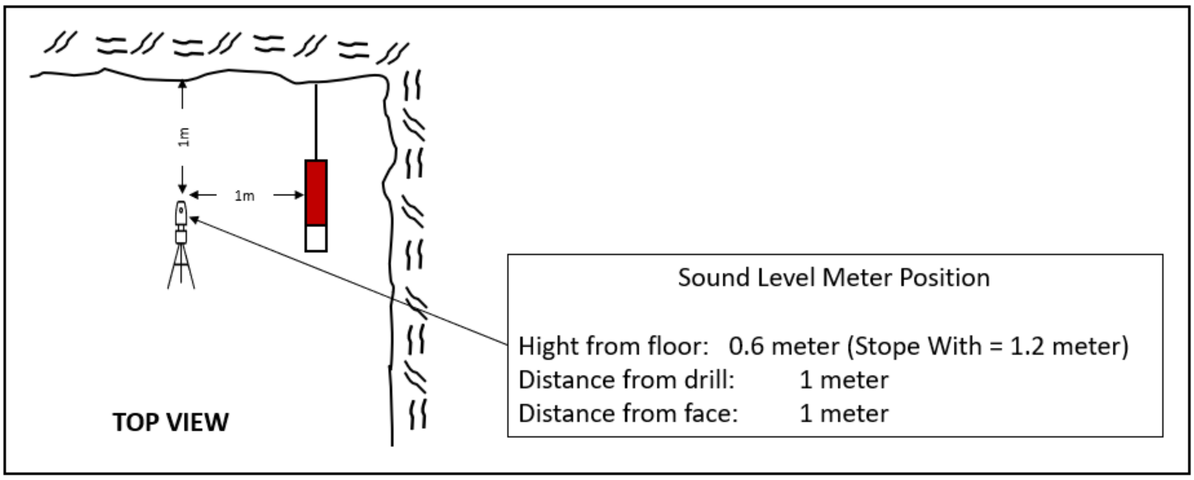


Figure 3.1: Sound Level Meter position during assessment of the HPD Rock Drill

Measurement Position for HPE Rock Drill (Isidingo Challenge)

The measurement position of the SLM were largely influenced by the risk associated with the working area and the rock drill position. The SLM were paced 1 meter from the footwall and 0,6 meters away from the handle of the rock drill (start of drilling position). The SLM could not be placed in at any position closer to the strike gulley face as this position could result in damage to the SLM, caused by the drilling activity, i.e., movement of the rock drill. Also see figure 3.2.

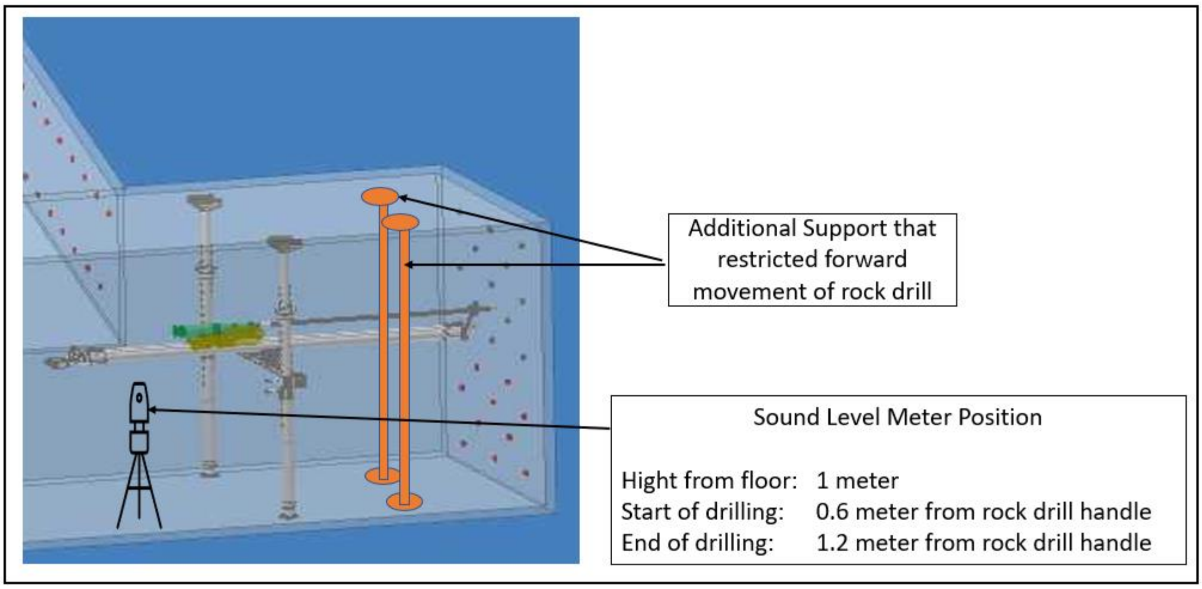


Figure 3.2: Sound Level Meter position during assessment of the NOVATEK Rock Drill

Occupational Exposure Limits (OELs)

Equipment noise levels will be evaluated against the Mine Health and Safety Council (MHSC) milestone for the quietening of equipment, i.e. "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).

The ISO defined guidelines, summarized as Table 1, to which the Hand-Arm Vibration findings from this report will be compared to.

Table 3.1 – ISO guidelines for HAV exposures

Vibration Type	ISO Guidelines	
	Exposure Action value (EAV)	Exposure Limit value (ELV)
Hand-Arm Vibration - A (8) (m/s^2)	2.5	5.0

FINDINGS AND RESULTS

Findings for Equipment Noise Levels

HPE Rock Drill (Isidingo)

A total of six measurements were recorded, namely:

- Recording 1: Background noise with rock drill not operational
- Recording 2: Rock drill operational but drill steel not touching the face / rock
- Recording 3: First test with the rock drill drilling a complete hole
- Recording 4: Second test with the rock drill drilling a complete hole
- Recording 5: Third test with the rock drill drilling a complete hole
- Recording 6: Fourth test with the rock drill not drilling a complete hole. This resulted due to movement of the guide plate installed on the face.

A summary of the recorded measurement for all frequencies is presented as figure 4.1. The detail recoded results for $^1/_3$ Octave Frequencies (ranging from 12.5 Hz to 20KHz) are attached as Appendix B.

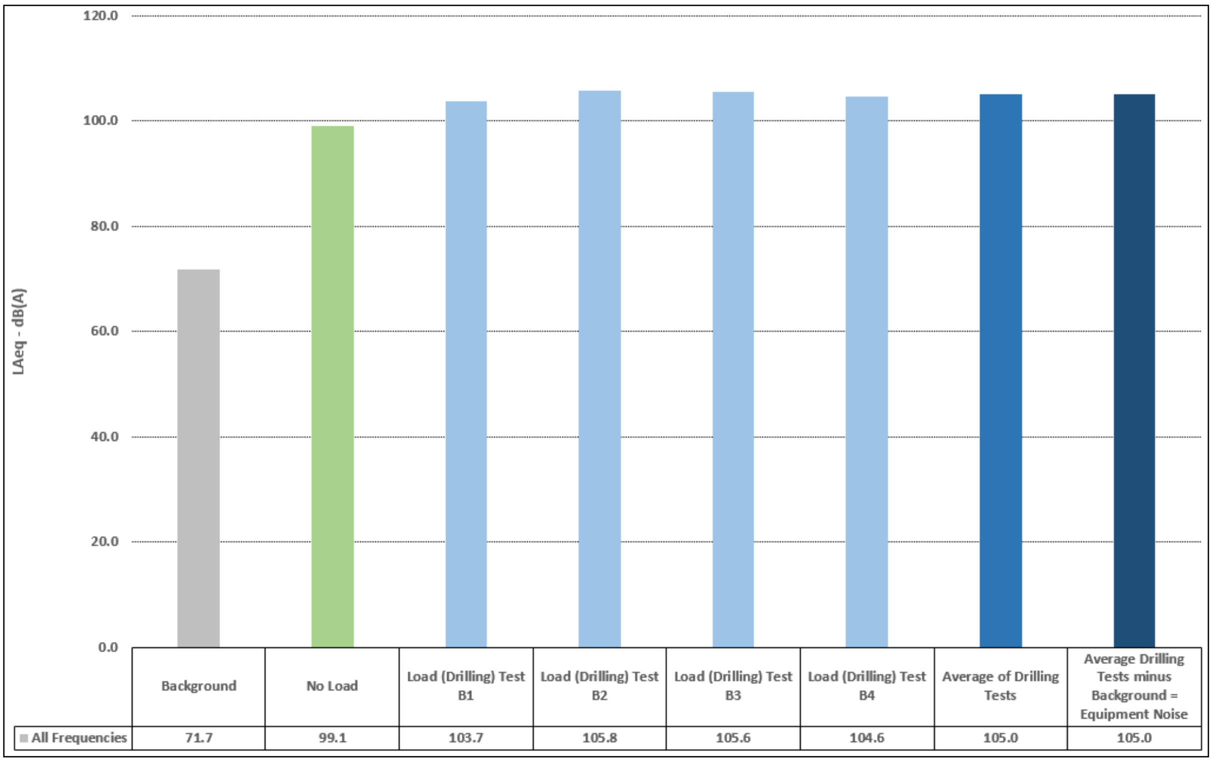


Figure 4.1: Summary of Noise Measurements recorded for the HPE Rock Drill (All Frequencies)

From the recorded noise data, it is evident that all recorded noise measurement were below the Mine Health and Safety Council Milestone sound level for equipment noise of 107 dB(A), measured as L_{Aeq}.

Novatek Rock Drill (Isidingo)

A total of seven measurements were recorded, namely:

- Recording 1: Background noise with rock drill not operational
- Recording 2: Rock drill operational but drill steel not touching the face / rock
- Recording 3: First test with the rock drill drilling an approximate 600mm hole
- Recording 4: Second test with the rock drill drilling an approximate 600mm hole
- Recording 5: Third test with the rock drill drilling an approximate 600mm hole
- Recording 6: Fourth test with the rock drill drilling an approximate 600mm hole
- Recording 7: Fourth test with the rock drill drilling an approximate 600mm hole.

Drilling of the hole depth were restricted to approximately 600mm due to the installation of additional temporary supports that prevented the drill from advancing beyond the temporary supports (see figure 3.2).

A summary of the recorded measurement for all frequencies is presented as figure 4.2. The detail recoded results for $^1/_3$ Octave Frequencies (ranging from 12.5 Hz to 20KHz) are attached as Appendix C.

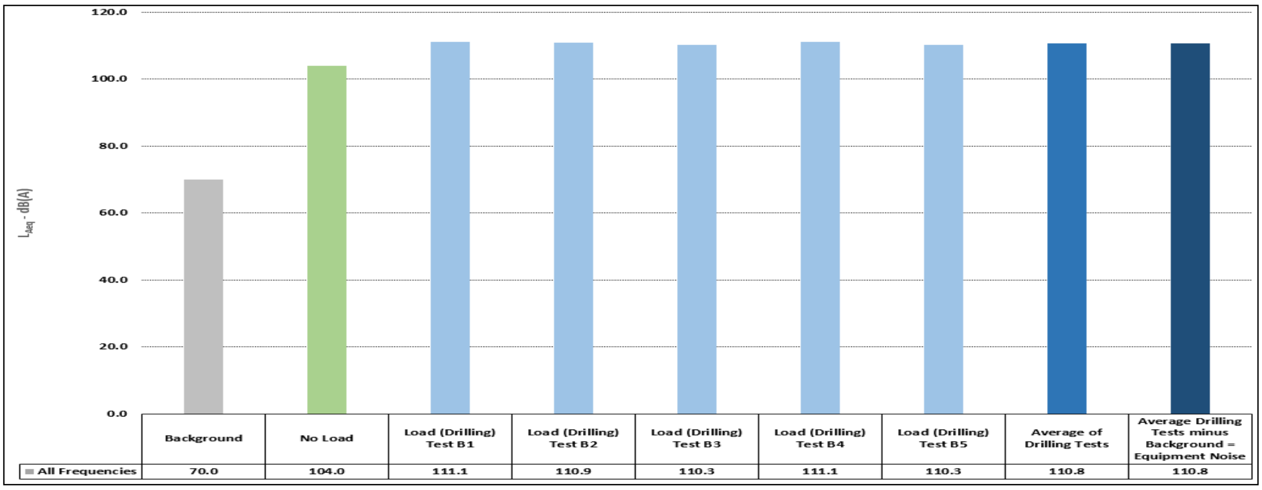


Figure 4.2: Summary of Noise Measurements recorded for the NOVATEK Rock Drill (All Frequencies)

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From the recorded noise data, it is evident that all operational recorded noise measurement were above the Mine Health and Safety Council Milestone sound level for equipment noise of 107 dB(A), measured as L_{Aeq}.

Hand-Arm Vibration Exposure Levels

HPE Rock Drill (Isidingo)

Daily vibration exposures were calculated from the data obtained for the HAV measurements for the trial rock drills presented. HAV exposures were calculated for exposures weighted as if the operator was exposed for 8 hours. **In addition**, the time allowed to operate the particular instrument **before** the exposure limits are reached, were also calculated, and included. For the purpose of this report, comparisons were made between the limit value of 5 m/s² with these exposure periods mentioned. Refer to Figure 4.3 for the tests conducted on the HPE trials and Figure 4.4 for the tests conducted on the Novatek trials.

The summarized findings for the HAV measurements for the HPE rock drill Tests are as follows:

HPE new technology rock drill - 12 Shaft						
Test 1 - No drilling load						
Axis	X	Y	Z	Overall HAV levels	Overall A(8)	Time to reach exposure (hours)
Vibration level (m/s²)	30,26	12,37	12,37	***34,96***	***34,96***	***8h***
Warning level (m/s2)					***2,5***	2 min
Maximum exposure level (m/s2)					***5,0***	10 min
Test 2						
Axis	X	Y	Z	Overall HAV levels	Overall A(8)	Time to reach exposure (hours)
Vibration level (m/s²)	25,78	9,68	11,46	***29,83***	***29,83***	***8h***
Warning level (m/s2)					***2,5***	3 min
Maximum exposure level (m/s2)					***5,0***	13 min
Test 3						
Axis	X	Y	Z	Overall HAV levels	Overall A(8)	Time to reach exposure (hours)
Vibration level (m/s²)	24,84	9,88	10,6	***28,75***	***28,75***	***8h***
Warning level (m/s2)					***2,5***	4 min
Maximum exposure level (m/s2)					***5,0***	15 min
Test 4						
Axis	X	Y	Z	Overall HAV levels	Overall A(8)	Time to reach exposure (hours)
Vibration level (m/s²)	29,88	9,03	12,85	***33,76***	***33,76***	***8h***
Warning level (m/s2)					***2,5***	3 min
Maximum exposure level (m/s2)					***5,0***	11 min
Test 5						
Axis	X	Y	Z	Overall HAV levels	Overall A(8)	Time to reach exposure (hours)
Vibration level (m/s²)	17,2	6,43	8,54	***20,25***	***20,25***	***8h***
Warning level (m/s2)					***2,5***	7 min
Maximum exposure level (m/s2)					***5,0***	29 min

Figure 4.3 – Daily HAV A (8) – underground rock drill trial – HPE trial

From the test results for the HAV levels measured for the HPE trail rock drill, it is evident that over-exposure to HAV levels will be reached between 11 to 29 minutes of operating this particular machine (refer to results represented in Figure 2.1 – Tests 2 to 5). These calculations were made based on the limit value of 5 m/s^2.

The exposure limit value (5 m/s^2), therefore, will be reached within these mentioned periods (11 to 29 minutes), after which the HAV levels will be such that it may cause symptoms such as tingling, loss of sensation in the fingers, loss of light touch and grip strength.

Test 1 was conducted when the drill was running with no load.

Novatek Rock Drill (Isidingo)

The summarized findings for the HAV measurements for the Novatek Isidingo rock drill Tests are as follows:

Novatek Isidingo new technology rock drill - 10 Shaft						
Test 1						
Axis	**X**	**Y**	**Z**	**Overall HAV levels**	**Overall A(8)**	**Time to reach exposure (hours)**
Vibration level (m/s^2)	19,42	13,87	40,34	***46,87***	***46,87***	***8h***
Warning level (m/s2)					***2,5***	1 min
Maximum exposure level (m/s2)					***5,0***	5 min
Test 2						
Axis	**X**	**Y**	**Z**	**Overall HAV levels**	**Overall A(8)**	**Time to reach exposure (hours)**
Vibration level (m/s^2)	41,34	41,63	55,39	***80,69***	***80,69***	***8h***
Warning level (m/s2)					***2,5***	
Maximum exposure level (m/s2)					***5,0***	2 min
Test 3						
Axis	**X**	**Y**	**Z**	**Overall HAV levels**	**Overall A(8)**	**Time to reach exposure (hours)**
Vibration level (m/s^2)	73,33	56,45	68,93	***115,39***	***115,39***	***8h***
Warning level (m/s2)					***2,5***	
Maximum exposure level (m/s2)					***5,0***	1 min
Test 4 - No drilling						
Axis	**X**	**Y**	**Z**	**Overall HAV levels**	**Overall A(8)**	**Time to reach exposure (hours)**
Vibration level (m/s^2)	14,43	19,36	17,01	***29,54***	***29,54***	***8h***
Warning level (m/s2)					***2,5***	3 min
Maximum exposure level (m/s2)					***5,0***	14 min

Figure 4.4 – Daily HAV A (8) – underground rock drill trial – Novatek Isidingo trial

From the test results for the HAV levels measured for the Novatek Isidingo trail rock drill, it is evident that over-exposure to HAV levels will be reached between 1 to 5 minutes of operating this particular machine (refer to results represented in Figure 2.2 – Tests 1 to 3). These calculations were made based on the limit value of 5 m/s^2.

The exposure limit value (5 m/s^2), therefore, will be reached within these mentioned periods (1-5 minutes), after which the HAV levels will be such that it may cause symptoms such as tingling, loss of sensation in the fingers, loss of light touch and grip strength.

Test 4 was conducted when the drill was running with no load.

Factors that may contribute to excessive vibration from rock drills include the following:

- Rock hardness.
- Air pressure to the drill (an uneven supply of air to the rock drill can cause increased impact when gripping the rock drill).
- Air pressure to the air leg (if applicable) - inadequate air supply to the air leg may cause difficulty in manipulation of the air leg.
- General maintenance of rock drills, i.e., loose parts, inadequate lubrication etc.).
- Condition of hammering mechanism of the rock drill; and
- Condition of drill bit and drill steel.

Additional HAV control measures:

- Anti-vibration handle (cushioned handles of rubber element) - vibration attenuating handle attempts to confront the problem of still having firm, stiff control of the tool, while at the same time reducing the vibration energy
- Anti-vibration gloves

APPENDIX A – Guidance note for noise measurement of equipment to ensure compliance with MHSC milestones

CHAMBER OF MINES
of South Africa

GUIDANCE NOTE FOR NOISE MEASUREMENT OF EQUIPMENT TO ENSURE COMPLIANCE WITH MHSC MILESTONES

FACT SHEET 2016

BACKGROUND

The Mine Health and Safety Council (MHSC) has established the following milestones for limiting occupational noise exposure and eliminating noise induced hearing loss (NIHL):

QUIETENING OF 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 MOSH, and reviewed in 2016."

FOR INDIVIDUALS

"By December 2016, no employee's Standard Threshold Shift (STS) will exceed 25 dB(A) from the baseline when averaged at 2000, 3000 and 4000 Hz in one or both ears."

PURPOSE

To manage the noise hazard effectively, industry focus must be on a strategy to eliminate and control noise at source by implementing an accepted, practical and effective industry-wide "buy and maintain quiet" initiative. This initiative is the outcome of a standing decision taken by mining companies to procure equipment/machinery and maintain existing equipment that conforms to specific noise emission requirements. This document serves as an industry guideline for the implementation of the 2014 noise milestones. It also details the required noise measurement procedure to ensure the employment of uniform measurement procedures under realistic operating conditions.

The guideline has been developed for use by persons who have been found competent to conduct noise measurements by virtue of their knowledge, training and experience.

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NOISE MEASUREMENT FOR INDIVIDUAL PIECES OF EQUIPMENT AND MACHINERY

MEASUREMENT CRITERIA

Noise levels should be measured directly with an integrating sound level meter (ISLM) that meets at least the accuracy requirements for a Class-2 instrument (given in IEC 61672-1 and SANS 61672-1), and is fitted with a windshield specified by the ISLM manufacturer. The following measurement criteria should be applied:

- Criterion level/exposure limit: 85 dB(A)
- Threshold level/low threshold limit: 80 dB(A)
- Energy exchange or doubling rate: 3 dB(A)

The instrument supplier normally sets these measurement criteria prior to delivery, but this should be confirmed before use. For instruments with a facility to alter measurement criteria via onboard software or firmware, the above criteria should be confirmed or corrected using the instrument's set-up mode.

INSTRUMENT SETTINGS

The following instrument settings should be used for $L_{Aeq,\,T}$ measurements:

- A-weighting: **on**
- Time weighting: **"fast" or "impulse"** if the noise is impulsive and the SLM has impulse-integrating capability. If the noise is impulsive but the SLM does not provide for impulse-integration, increase the measured $L_{Aeq,\,T}$ by 5 dB(A) for moderately impulsive noise (e.g. pneumatic rock drill) or 12 dB(A) for highly impulsive noise (e.g. compressed air-driven charging-up of blast holes or hammer blows in an artisan workshop)
- Sound incidence: where applicable, **"frontal"** if the microphone is facing a noise source, or **"random"** if the noise is non-directional/ multi-directional
- Frequency filter: **out** (off)
- Operating mode: **integrate or L_{Aeq}**

GENERAL PROCEDURES

The following general procedures must be followed for $L_{Aeq,\,T}$ measurements:

- Confirm the SLM's acoustic sensitivity with a sound calibrator immediately before and after each series of measurements, usually before commencing a shift and immediately after completion of the shift. This should be done using Class 2 calibrator (minimum) as defined in SANS 60942/SABS-IEC 60942. If the two calibration checks do not coincide to within 1 dB(A) [SANS 10083:2013], results of the intervening measurements must be discarded and the measurements repeated.
- For the purpose of measuring individual pieces of equipment and machinery, measurements should be taken 1m away from the specific noise source.

MEASUREMENT PROCEDURES

Measure $L_{Aeq,\,T}$ for a representative time at a selected microphone position:

- For steady noise, a measurement time of 1 minute is adequate.
- Where the noise varies or is cyclical, the measurement time should be sufficient to capture variations in level and include a reasonable number of work task cycles, to ensure representative results. This $L_{Aeq,\,T}$ measurement for the variation or cyclical noise level will then be recorded as the representative noise level for the individual piece of equipment or machine.

NEW (TYPE/DESIGN) EQUIPMENT REQUIREMENTS

Noise measurements must comply with ISO 3744/SANS3744:2012. As a rule of thumb, the impact of the noise emitted from a new type or design of equipment underground can be estimated by doubling the noise level measured on surface. This is achieved by adding 3dB(A) to the noise level displayed on the manufacturer's certificate to allow for sound reflected from solid boundaries (reverberation).

REPORTING AND RECORDING RESULTS OF NOISE MEASUREMENTS

Data collection

- For equipment noise emissions above 100 dB(A), the data collection will be based on sampling a minimum of 5% (or a minimum of 5 if there is less than 100 pieces of that particular equipment type) of that equipment type total population over a 12-month period (samples should be representative of the various activities)

- The **logarithmic average** must be calculated for reporting purposes per quarter.

The following formula can be used to calculate the logarithmic average (L_{Aeq}):

$$L_{Aeq} = 10 \log \left(anti \log \frac{L1}{10} + anti \log \frac{L2}{10} + anti \log \frac{L3}{10} + anti \log \frac{L4}{10} + \ldots \right)$$

Where: L = the noise levels measured (L_{Aeq}) in dB(A) for equipment.

EXAMPLE: (MINIMUM OF 5% OR A MINIMUM OF 5 OVER A 12-MONTH PERIOD)

Rock drill 1 = L1 = 105.0 dB(A)
Rock drill 2 = L2 = 103.8 dB(A)
Rock drill 3 = L3 = 108.2 dB(A)
Rock drill 4 = L4 = 104.6 dB(A)

$$L_{Aeq} = 10 \log \left(\frac{anti \log \frac{105.0}{10} + anti \log \frac{103.8}{10} + anti \log \frac{108.2}{10} + anti \log \frac{104.6}{10}}{n} \right)$$

L_{Aeq} = 105.8 dB(A)   n = number of total samples

CALCULATION OF THE LOGARITHMIC AVERAGE

For quarter 1 the logarithmic average for the quarter is calculated using readings 1, 2, 3 and 4 as indicated below. The same applies to calculate the log average for the quarter going forward.

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Log Average	105.8	105.4	103.9	106.0
Log Average for quarter		105.6	104.8	105.3
Reading (1)	105.0	104.1	105.7	105.0
Reading (2)	103.8	105.6	99.9	103.8
Reading (3)	108.2	106.9	104.2	108.2
Reading (4)	104.6	104.2	–	104.6
Reading (5)	–	–	–	106.9

CALCULATION OF THE ROLLING LOGARITHMIC AVERAGE

To calculate the logarithmic rolling average for quarter 2, readings 1, 2, 3 and 4 of quarter 1 as well as readings 1, 2, 3 and 4 of quarter 2 are used as indicated below. The same applies for the next quarters.

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Log Average	105.8	105.4	103.9	106.0
Log Average for quarter		105.6	104.8	105.3
Reading (1)	105.0	104.1	105.7	105.0
Reading (2)	103.8	105.6	99.9	103.8
Reading (3)	108.2	106.9	104.2	108.2
Reading (4)	104.6	104.2	–	104.6
Reading (5)	–	–	–	106.9

For equipment between 85 dB(A) and 100 dB(A) data collection will be based on the noise risk register as follows:

- Identify the equipment to be measured
- Determine background area for the measurement
- Identify the equipment that can be switched-off safely
- Switch-off the identified equipment
- Record the background noise
- List the equipment that could not be switched off during the recording of the background noise
- Record equipment noise ***(Refer to the example in Appendix 1)***

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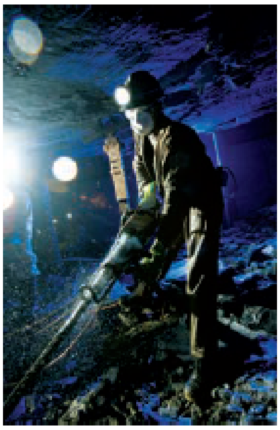
DATA REPORTING

- Noise data will be reported using rolling log averages on a quarterly basis
- Total number of pieces of equipment type must be reported quarterly

Results should be recorded and documented so as to ensure uniform workplace operating conditions, measurement procedures and microphone positions, thereby allowing meaningful comparisons with future results. The following information must be recorded:

- **Instrument type, serial number (including microphone), calibration date, etc.**
- **Working place, environmental and equipment information such as:**

- Mining company
- Mine/shaft/operation
- Commodity
- Type of mining
- Workplace (use SAMOHP Code e.g. stoping, development, etc.)
- Excavation area (m²)
- Type of excavation
- Equipment being measured – name and description
- Model/type
- Serial/equipment number
- Equipment category
- Power source (pneumatic/electric/ electro hydraulic/hydro power)
- Manufacturer/supplier
- Activities/processes measured
  - Activities – equipment that runs continuously e.g. pump, compressor, etc.
  - Process – cyclical operations e.g. rock drill collaring, drilling and extracting, etc.
- Silenced/not silenced
- Number of pieces of equipment per shaft
- Noise level (dBA) – (log average to be recorded
- Noise level (dBA) – all scenarios (maximum to be recorded)
- Type of ventilation
- Air velocity
- List background noise levels and the sources that constitute the background noise
- Compressed air pressure for pneumatic-driven equipment
- Date of report



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REFERENCES

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SANS 61672-1 – Electro-acoustics – Sound level meters Part 1: Specifications

SANS 60942 – Electro-acoustics – Sound calibrators

IEC 60942 – Electro-acoustics – Sound calibrators

SANS 10083:2013 – The measurement and assessment of occupational noise for hearing conservation purposes

ISO 3744 – Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane

SANS3744:2012 – Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane

Mine Ventilation Society of South Africa, learning material for the Certificate in Mine Environmental Control, workbook 5

APPENDICES

Appendix 1 – Example of equipment noise measurement process

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APPENDIX B – Detailed recorded Sound Level Meter results for the HPE Rock Drill

	L_{Aeq} (dB)							
Frequency	**Background**	**No Load**	**Load (Drilling) Test B1**	**Load (Drilling) Test B2**	**Load (Drilling) Test B3**	**Load (Drilling) Test B4**	**Average of Drilling Tests**	**Average Drilling Tests minus Background = Equipment Noise**
12.5 Hz	10.4	7.8	8.7	18.3	12.9	11.3	14.3	12.1
16 Hz	15.0	14.8	14.7	20.4	19.5	17.3	18.5	15.9
20 Hz	16.3	17.9	16.3	20.5	19.8	19.6	19.3	16.3
25 Hz	16.4	17.2	16.6	19.5	18.9	23.8	20.5	18.4
31.5 Hz	29.7	30.5	30.6	30.0	31.3	35.0	32.2	28.6
40 Hz	36.1	44.6	42.8	39.0	42.8	42.4	42.0	40.7
50 Hz	38.8	57.0	57.6	55.2	55.9	55.5	56.2	56.1
63 Hz	37.0	39.8	50.3	51.0	51.3	51.0	50.9	50.7
80 Hz	44.5	46.5	46.4	46.0	47.0	47.0	46.6	42.5
100 Hz	43.5	47.9	54.5	58.4	53.9	52.1	55.4	55.1
125 Hz	49.8	62.2	56.3	57.3	59.0	56.9	57.5	56.7
160 Hz	53.5	64.6	62.1	67.4	61.8	63.6	64.4	64.0
200 Hz	54.6	70.8	66.1	68.4	63.5	64.9	66.1	65.8
250 Hz	57.2	67.3	68.1	75.4	67.9	70.7	71.7	71.5
315 Hz	61.3	78.3	78.6	78.5	76.2	77.9	77.9	77.8
400 Hz	59.3	86.4	78.5	82.3	77.1	76.9	79.3	79.3
500 Hz	64.5	84.7	82.1	81.6	79.8	80.4	81.1	81.0
630 Hz	67.7	82.7	83.1	83.4	85.4	83.4	83.9	83.8
800 Hz	66.4	87.2	87.4	86.1	87.6	86.9	87.0	87.0
1 kHz	63.5	87.2	90.3	90.3	90.6	90.1	90.3	90.3
1.25 kHz	65.5	86.8	91.5	94.2	93.0	92.9	93.0	93.0

1.6 kHz	64.5	88.5	93.2	96.4	96.7	95.5	95.6	95.6
2 kHz	64.0	85.3	90.9	92.1	91.3	91.2	91.4	91.4
2.5 kHz	64.1	85.2	92.8	93.3	93.7	92.3	93.1	93.1
3.15 kHz	64.8	88.2	94.9	96.7	95.9	94.8	95.6	95.6
4 kHz	65.5	90.0	95.4	97.8	97.2	96.1	96.7	96.7
5 kHz	64.7	90.0	94.5	97.0	97.3	96.3	96.4	96.4
6.3 kHz	63.3	87.2	93.9	96.3	96.0	95.1	95.4	95.4
8 kHz	61.3	87.8	92.5	95.5	94.9	93.7	94.3	94.3
10 kHz	59.0	85.1	88.4	91.6	91.7	90.0	90.6	90.6
12.5 kHz	56.0	78.8	83.2	84.8	85.3	84.2	84.4	84.4
16 kHz	51.7	69.3	73.8	75.5	75.2	74.5	74.8	74.8
20 kHz	40.4	58.2	67.6	69.0	68.7	67.9	68.3	68.3
All Frequencies	71.7	99.1	103.7	105.8	105.6	104.6	105.0	105.0

APPENDIX C – Detailed recorded Sound Level Meter results for the NOVATEK Rock Drill

Frequency	L_{Aeq} (dB)								
	Background	No Load	Load (Drilling) Test B1	Load (Drilling) Test B2	Load (Drilling) Test B3	Load (Drilling) Test B4	Load (Drilling) Test B5	Average of Drilling Tests	Average Drilling Tests minus Background = Equipment Noise
12.5 Hz	13.0	13.7	15.0	14.1	14.3	13.5	14.3	14.3	8.3
16 Hz	23.5	25.6	24.9	24.7	24.4	24.3	24.8	24.6	18.2
20 Hz	21.3	22.1	22.8	21.8	22.1	21.0	22.9	22.2	14.8
25 Hz	10.8	14.6	23.3	22.7	23.4	26.0	22.9	23.8	23.6
31.5 Hz	11.7	33.8	31.3	34.0	32.2	32.2	34.1	32.9	32.9
40 Hz	20.6	35.7	35.1	34.1	36.7	38.6	35.7	36.3	36.2
50 Hz	39.5	37.3	41.8	40.7	44.3	43.8	40.8	42.5	39.6
63 Hz	50.8	46.3	54.6	53.4	55.0	56.1	54.6	54.8	52.6
80 Hz	40.4	46.4	49.6	48.5	44.9	47.6	46.2	47.7	46.8
100 Hz	45.6	50.9	50.7	50.1	53.0	53.2	50.0	51.6	50.4
125 Hz	53.2	57.3	60.7	63.2	63.6	62.6	63.6	62.9	62.4
160 Hz	43.8	61.2	63.0	62.7	63.8	66.5	63.9	64.2	64.2
200 Hz	43.6	62.4	71.0	68.5	69.6	70.0	69.5	69.8	69.8
250 Hz	42.0	68.2	73.2	71.5	71.2	71.5	69.9	71.6	71.6
315 Hz	43.0	74.3	75.0	72.6	72.7	73.7	72.9	73.5	73.5
400 Hz	46.7	78.7	80.1	78.0	78.6	77.4	77.5	78.4	78.4
500 Hz	46.3	77.8	80.3	78.8	78.9	82.6	79.6	80.3	80.3
630 Hz	46.9	81.4	83.8	83.6	83.1	84.3	82.7	83.5	83.5
800 Hz	42.3	82.0	85.8	86.7	84.7	86.7	85.5	85.9	85.9
1 kHz	38.9	87.8	90.8	90.7	90.4	91.9	90.4	90.9	90.9

1.25 kHz	38.9	90.1	94.4	94.2	94.6	95.5	94.0	94.6	94.6
1.6 kHz	38.4	93.4	97.4	97.0	96.4	98.1	96.7	97.2	97.2
2 kHz	37.7	93.6	98.8	98.4	97.9	98.9	98.0	98.4	98.4
2.5 kHz	37.7	96.1	101.8	101.4	101.2	102.4	101.5	101.7	101.7
3.15 kHz	36.3	94.6	103.1	103.0	102.8	103.1	102.3	102.9	102.9
4 kHz	38.7	94.6	103.8	103.4	102.7	103.4	103.3	103.3	103.3
5 kHz	38.7	94.1	103.0	102.6	102.1	103.2	102.2	102.6	102.6
6.3 kHz	39.0	93.7	101.4	101.7	100.6	101.5	100.6	101.2	101.2
8 kHz	38.4	94.0	100.4	100.7	99.5	100.0	98.8	99.9	99.9
10 kHz	36.7	89.8	96.5	96.8	94.8	95.3	94.2	95.6	95.6
12.5 kHz	33.9	82.4	90.0	89.9	89.2	89.4	88.3	89.4	89.4
16 kHz	30.5	74.4	83.1	83.0	82.3	82.8	81.6	82.6	82.6
20 kHz	27.4	65.9	74.9	75.0	74.1	74.7	73.4	74.5	74.5
All Frequencies	**70.0**	**104.0**	**111.1**	**110.9**	**110.3**	**111.1**	**110.3**	**110.8**	**110.8**

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Annexure B: Recommended guideline for stakeholder participation in equipment design and development for the South African mining sector

Step Title	**1. Demand Analysis**	**2. Product Specifications**	**3. Equipment Design and Development**	**4. Demonstration, Pilot, Review and Refinement**	**5. Adoption**
Description	The need for equipment design and development is investigated in a formal manner to understand the drive and possible value contribution of the operation and stakeholders	Technical specifications for the use of the equipment are developed, based on regulatory requirements, ergonomic factors, best practice technical guidelines	Technical specification implementation of the equipment design and development, which could include SHEQ alignment, specialised consulting, technical guideline initiation and regulatory alignment	The demonstration of the use of the equipment through various prototype testing/modelling/simulations and practical alignment or realignment to standards and requirements	The process of technology transfer to end-user level usage including transfer of required skills and technical guidelines
Process Underpin	1.1. Business case 1.2. Context of use definitions (scenarios of use), which include the technical, physical, social, cultural, and organisational environments 1.3. Stakeholder identification 1.4. SHEQ Analysis 1.5. Organisational impact assessment	2.1. Technical specification determination 2.2. Regulatory analysis 2.3. Environmental analysis 2.4. Ergonomic factor analysis 2.5. Best practice benchmarking	3.1. Concept development 3.2. Technical specification analysis 3.3. SHEQ requirement inclusion 3.4. Specialised technical development and inputs 3.5. Projections and modelling	4.1. Prototyping and organisation practical testing (mock-up trials) 4.2. User testing, feedback and alignment (if required) 4.3. Further technical guideline development 4.4. Verification and validation	5.1. Skills transfer 5.2. Technology transfer to user 5.3 Application / commissioning and review
Methodology (Examples)	• Brainstorming • Benchmarking best practice • Idea generation methods	• Benchmarking • OEM specification • Regulatory specifications	• Organisational prototyping • Design guidelines and standards	• Model run • Broader simulations	• Skills transfer • User and technical guideline distribution and implementation

	• Field studies • Surveys • Observations • Technical steering committee establishment and inputs provided • Environmental analysis • Cost-benefit analysis • Role play • Context diagram	• Ergonomic guidelines • Focus group discussions • Surveys • Desktop study	• Virtual reality (VR) design and projections • Lead user analysis • National/international modelling	• Projections (scenario, production, financial, other) • Physical demonstration (prototype concept and site/mock-up demonstration) • VR and simulations	• Standard operating procedures implemented • Post-delivery support • Refer to change guideline • Communication strategies rolled out
Possible Stakeholder Involved	• Driver: industry / mine management • Lead: OEMs • Mine technical services (e.g. engineering, safety, production) • Support services at mines (e.g. ICT, training, HR, OHS, finance, procurement, legal) • External consultants (e.g. SHEQ, technical designer, programmers) • Indirect input from the workforce from all job grades (e.g. operators, artisans, supervisors, miners, shift bosses) • Labour representatives (if relevant) • Regulator (if relevant) • Etc.	• Industry / mine management, including technical and support services • OEMs • External consultants • Suppliers (if relevant) • Labour representatives • Workforce • Regulator (if relevant) • Etc.	• OEMs • Industry / mine management, including technical and support services • External consultants (if relevant) • Suppliers • Labour representatives • Workforce (direct participation) • Regulator (if relevant) • Etc.	• OEMs • Industry / mine management, including technical and support services • External consultants (if relevant) • Suppliers (if relevant) • Labour representatives • Workforce (direct participation) • Regulator • Communities • Etc.	• OEMs • Industry / mine management, including technical and support services • External consultants (if relevant) • Suppliers (if relevant) • Labour representatives • Workforce (direct participation) • Regulator • Communities • Etc.
Underpinning Factors	Loop Learning (single, double and triple loop), including hazard analysis Change Management (monitoring and evaluation – communication strategies) Impact on Jobs and Skills Requirements				