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**THE SOUTHERN AFRICAN INSTITUTE OF MINING AND METALLURGY
JOHANNESBURG 2024**



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T. Balfour
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FOREWORD

The South African mining industry has recorded 34 fatalities in the year to date compared to 39 this time last year. The number of occupational reportable injuries is 13% lower, with 1545 of our colleagues hurt while at work so far this year. The industry has however realised significant reductions in mining incidents and particularly fatalities over the last three decades through initiatives such as the Khumbul'ekhaya CEO-led strategy which has had a significant impact over the last five years. Through the industry's Fall of Ground Action Plan (FOGAP), there was a record low of six fatalities in 2022, a 97% reduction from the 239 FOG-related deaths reported in 1994. Transport and machinery-related fatalities have similarly decreased, falling by 91% to eight from 87 three decades ago. This is another example that through our unwavering focus on these historical agencies that led to fatalities, we are making a positive difference in creating a safer working environment.

This year the conference is once again focused on improving safety, health and environmental practices within the mining and metallurgical industry. It is an ideal platform for knowledge-sharing and idea exchange among various stakeholders, including mining companies, the Department of Mineral and Petroleum Resources, the Minerals Council South Africa, labour unions, and health and safety practitioners at all levels within the industry.

The main objectives of the conference are as follows:

Promoting Learning: The conference aims to facilitate a space where attendees can learn from each other's experiences and best practices. This will help enhance overall safety and environmental standards in the mining and metallurgical sector.

Addressing Safety, Health, and Environment: The conference will focus on discussions related to safety and health issues within the industry, including the well-being of employees, contractors, and local communities. Presentations on health and safety culture improvement, risk and control management and human factors will provide major insights into improving safety and health in companies. The conference will also emphasise the importance of reducing the environmental impact of mining and metallurgical processes.

Zero Harm and the elimination of fatalities: The conference will highlight the importance of adopting a 'zero harm' approach to health and safety in the mining and metallurgical sector. This means striving for an injury-free and accident-free workplace through tangible actions and leadership commitment at all levels.

Addressing Key Challenges: The conference will tackle major challenges in the mining industry, such as logistics, energy usage, and safety concerns related to employees, contractors, and communities.

By bringing together diverse stakeholders and sharing their expertise and experiences, this conference hopes to foster a safer and more sustainable mining and metallurgical industry. It emphasises the importance of collaboration and collective efforts to address the complex challenges faced by the sector.

L. McMaster

Chairperson of the Organising Committee

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PREMIUM EXHIBITOR



EXHIBITOR



Algorithms and data: A strategy for the successful implementation of machine learning in rock engineering to enhance safety

R.T. Masethe¹ and A.C. Adoko²

¹University of KwaZulu-Natal, South Africa

²Nazarbayev University, Kazakhstan

Despite many advances in rock engineering designs where safety has been improved in recent years through the adoption of leading practices, accidents and fatalities still occur. Striving to improve designs and behaviour to achieve the objective of every mine worker returning daily from work unharmed is still a vision that needs to become reality. Machine learning (ML) has become increasingly important in rock engineering, offering new ways to enhance safety in the design and operation of rock structures (e.g., tunnels, mining stopes, slopes, etc.). ML enables rock engineering practitioners to increase the efficiency and usage of massive data sets during the design process as rock engineering moves into the next era and becomes more data-driven. Despite being a potent tool, ML algorithms' success is inextricably linked to the calibre and volume of available data.

Keywords: machine learning, predictions, data driven, risk, algorithms, deep learning, numerical modelling.

INTRODUCTION

Safe ore extraction has improved in South African mines, especially those that are cognisant of rockburst phenomena. This has been achieved through the improvement of rock engineering designs, miners' behaviour modification, and underground support improvement through the adoption of the Mine Health Safety Council industry-leading practices. These include minimising rock mass damages, eliminating the risk of working under unsupported rock, and improving underground visibility to an appropriate standard. It has been an odyssey for the industry to eliminate fall of ground serious injuries by ~ 90% from 62 in 2009 to six in 2022. This is an indication that early interventions and the fall of ground action plans are working. For the South African mining industry to achieve zero harm, artificial intelligence (AI) [e.g., ML or deep learning (DL)] might be an aid due to its newness in transitioning the industry into the next industrial era, as we can no longer rely solely on human behaviour for decision-making (Chimunhu, Topal *et al.*, 2022, Azhari, Sennersten *et al.*, 2023).

The implementation of the Fall of Ground Action Plan (FOGAP)

In the South African context, the number of falls of ground (FOG) related fatalities has reduced by 94% for the last 15 years from 239 in 1994. The industry reported a record low of six FOG fatalities in 2022, indicating that the FOG action plan and earlier interventions are working (Figure 1). The reduction in FOG fatalities and the 91% decline in transport and mining deaths to eight from 87 30 years ago has contributed significantly to fatalities decreasing by 88% to 55 last year from 484 in 1994. While the reduction is commendable, more work is needed to achieve the industrial vision of zero harm (MINCOSA, 2024)).

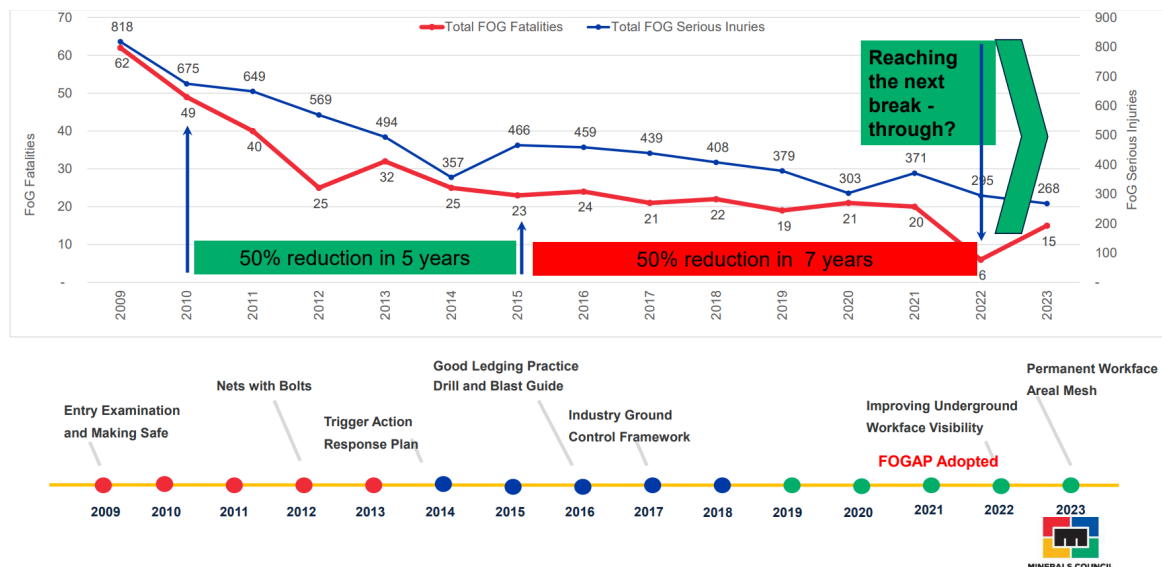


Figure 1. Improvement in FOG fatalities and serious injuries in the mines (MINCOSA, 2024).

More instrumentation data is being collected by operating mines and underground infrastructure projects (e.g., hydrofracturing, closure, rock explosions, slope deformation, etc.). However usually only a small portion of the critical data is taken out for rock engineering design; a thorough examination of complex geological formations often necessitates a longer period of time. We anticipate seeing even more AI and ML breakthroughs as their use in mining grows. As technology develops, AI-powered sensors are anticipated to advance in sophistication, accuracy, and predictive capacity. AI-powered virtual reality technologies could be used to test new technologies before they are implemented onsite and to replicate mining scenarios. AI-powered systems and devices will be even more connected with the introduction of 5G networks, enabling real-time data processing and quicker decision-making.

Review of Machine Learning algorithms

AI is not a new tool, having its roots from as far back as the 1940s and 1950s when it was introduced by the likes of Alan Turing, Alan Hodgkin, and Andrew Huxley (the latter two are known for the Hodgkin-Huxley algorithm) (Zaremba & Smoleński, 2000; Hodgkin & Huxley, 1952). It developed steadily over the years, with cybernetics, neural networks, and expert systems being some of the milestones. Improvements in computing capability, the internet, and the generation of large amounts of data in the past 17 years or so have seen an exponential rise in the development and adoption of AI, especially in ML and DL. This has seen wide applications e.g., in prediction of natural disasters such as tornadoes (Abad & Iyengar, 2015) and tsunamis (Marras & Mandli, 2021); health care (Kourou *et al.*, 2015); agriculture (Liakos *et al.*, 2018); speech recognition and natural language processing (Van Houdt *et al.*, 2020) and some water studies (Kirthana & Soumya, 2020; Bernardelli *et al.*, 2020; Al-Adhaileh & Alsaade, 2021; Ramli *et al.*, 2018).

ML has become increasingly crucial in rock engineering, offering new ways to enhance safety in the design and operation of rock structures (e.g., tunnels, stopes, slopes, etc.). It is the scientific study of algorithms and statistical models that computer systems employ to carry out a given task based on patterns and hypotheses without using detailed instructions and commands. The ML algorithms create a mathematical model using sample data, known as the training dataset, to make predictions or decisions without the need to programme them to do the task (Singh & Dhiman, 2021).

The subsets of AI (e.g., ML and/or DL) in rock engineering will be the next ground-breaking chapter in the South African mining industry to improve safety through enhanced designs and digitalisation. As the new transitioning era unfolds, the use and advancement of technology in different sectors will become a way of life with a surge in the utilisation of machines and DL methodologies. Rock

engineering should adopt the use of this subset of AI (Figure 2). As rock engineering becomes more data-driven ML can improve the efficiency and the utilisation of huge data sets in the design process.

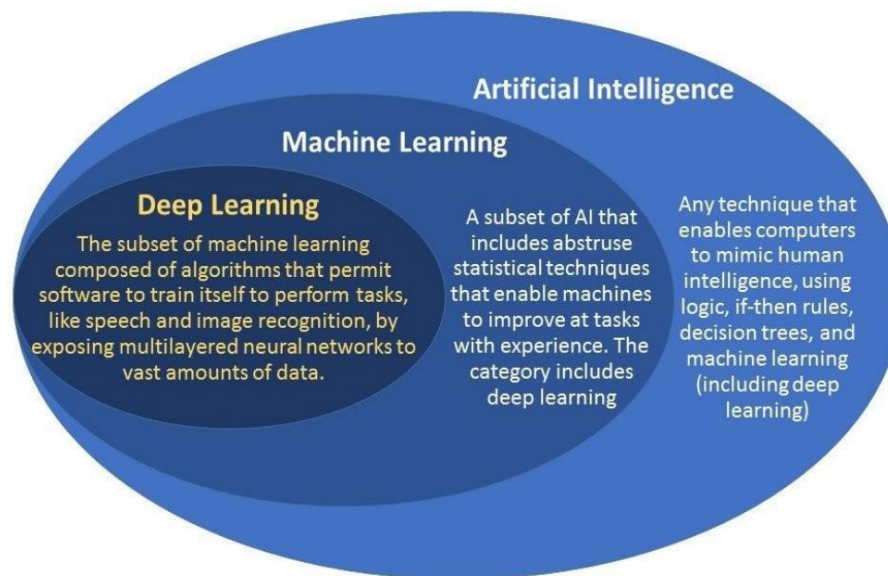


Figure 2. Artificial intelligence, machine learning and deep learning – relationship.

There are many ML algorithms, and the theoretical background of these methods can be found in the literature. This includes regression, ensemble, clustering, decision trees, Bayesian, neural networks, rule systems, and many more that have been used across many disciplines (Figure 3).

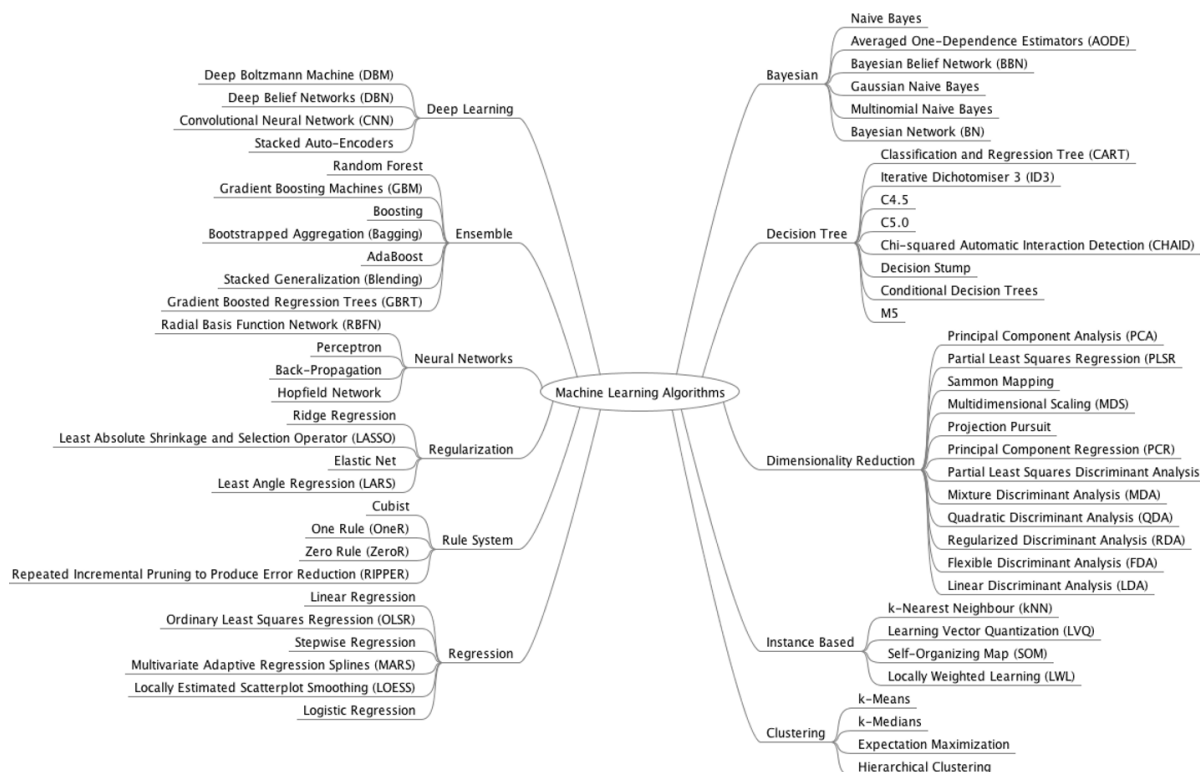


Figure 3. Mindmap of different types of machine learning algorithms.

These algorithms operate differently and cater to different sorts of problems. The choice of ML techniques is informed by the output and data available (Mohammed *et al.*, 2016). Different ML algorithms are described by grouping them based on learning styles and similarities. The most popular method of grouping ML algorithms is based on how they interact with the initial dataset, giving rise to different learning styles. There are four main learning styles, i.e., supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning.

- Supervised learning – labelled datasets that train or supervise the algorithm in classifying or predicting outcomes. The algorithm employs predefined variables for both input and output, establishing a link between them (Newhart *et al.*, 2019).
- Unsupervised learning – algorithms use a set of unlabelled datasets. There is no target variable for estimation or prediction in unlabelled datasets. The algorithm discovers patterns and similarities in the data, and then the ML system uses the differences to generate outcomes (Anowar *et al.*, 2021).
- Semi-supervised learning – labelled and unlabelled datasets. The latter is frequently found in higher amounts because it is less costly and more accessible. The algorithm develops an agent interacting with its environment, which can be the initial dataset. Semi-supervised contains a mixture of labelled and unlabelled data.
- Reinforcement learning – no data; the algorithm matches situations to actions to maximise a reward.

Current Practices in Rock Engineering Design

In rock engineering design, the two most popular design approaches are (i) empirical methodologies and (ii) numerical modelling. These are typically integrated into a workflow based on the level of design, from thorough design to viability. The empirical design recommendations are frequently used as a starting point, and then, depending on the geometry and complexity of the problem, we verify and update them using the appropriate numerical tools. However, in both cases, rock engineers and practitioners employ their judgment to combine categorical data (e.g., discontinuity conditions and geological mapping) and numerical data (e.g., rock mass properties, stress conditions, and pore water pressure) into an empirical or numerical framework. The following is a list of traditional methods for support recommendations.

Empirical Design

Various materials may be used to create the intended rock support, including shotcrete, steel mesh, concrete liner segments, steel straps, and rock or cable bolts. These techniques are only used as a preliminary estimate, with analytical or numerical approaches employed to verify the design. They typically depend on the extent of the excavation and the quality of the rock mass. It is common practice to employ several empirical techniques and a range of input parameters representing best- and worst-case scenarios to generate a range of rock support suggestions. This section describes two popular empirical rock support methodologies: rock mass rating (RMR) and the Q system.

Rock Mass Rating

Bieniawski established the RMR categorisation method; the system generates a score between 0 and 100 by adding the five fundamental parameters: strength of the intact rock, rock quality designation (RQD), joints spacing, joints condition, and groundwater condition. Both field mapping and site investigation are used to obtain the information. Based on a linear relationship between the RMR value and rock quality, the RMR correlates to a rock quality category ranging from very good to very poor rock encompassing five distinct classes. Bieniawski developed support guidelines to evaluate rock mass quality.

Q tunneling system

Barton *et al.*, (1974) developed the rock tunnel quality index (Q system) based on 212 case studies of underground excavation. Although an independent system, it has some parameters in common with RMR, e.g., rock quality designation and ground water. The Q system, defined by multiplying three quotients – the size of the rock blocks, the frictional resistance and roughness – and the stress quotient was mainly designed to forecast the suitable support for tunnels. Similar to RMR, the parameters are

gathered during a project's site study phase, and the most representative value or values are then determined through statistical analysis. The formula for the Q system, which has a value between 0.001 and 1000, is given in Equation (1):

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \quad (1)$$

where:

RQD = Rock quality designation

J_n = Number of joint/fracture sets

J_r = Roughness of most unfavourable joints

J_a = Alteration or infilling of joints

J_w = Water inflow

SRF = Stress reduction factor, quantifies stress conditions

Numerical Models

To complete rock engineering designs and evaluate the behaviour of intact rocks and rock masses, numerical modelling is needed. These techniques identify the mechanisms underlying phenomena seen in an intact rock sample or rock mass and then incorporate the mechanisms into the design. Selecting inputs, geometry, boundary, and stress conditions, among other key elements of a numerical model, necessitates a high degree of engineering judgement in addition to combining quantitative and qualitative site observations. A standard method is to calibrate the behaviour of numerical models against observed site circumstances using back analysis. The behaviour of the excavation is then forward predicted using these calibrated models as the excavation progresses. The most common standard numerical model in rock engineering problems are, according to (Jing and Hudson, 2002), the continuum method (e.g. finite element modelling, finite difference modelling, boundary element modelling, discrete methods (e.g., discrete element modelling and discrete fracture network modelling, and lastly the hybrid continuum/discrete methods. The complexity of the problem being solved, and the data provided, determines the most appropriate numerical methodology. Several methods may be investigated before one is chosen for further design activities. Much expert judgement (e.g., rock engineers) is needed to identify the model inputs and evaluate the outputs, just as in empirical design approaches.

Discussion of the current Rock Engineering Practices

Both empirical and numerical approaches have their roots in traditional rock mechanics design and provide information about the expected response of the rock mass to excavation construction. The problems frequently do not lie in the methodologies but from the way the data is entered into numerical models or utilised to inform support decisions. Error is introduced into the design process by the intrinsic variability of rock engineering datasets and their range of types (numerical measurements, category descriptions, photographs). It is standard practice to employ statistical analysis or the best-and worst-case values to calculate the rock mass categorisation value when using empirical support recommendations. Although this is suitable for a preliminary feasibility assessment, these considerations are occasionally extended to a comprehensive design. A data-driven approach would enable the design engineer to utilise all available data to determine the best parameters for future applications.

Discussion of the Machine Learning for Rock Engineering Designs

ML algorithms have been applied in different rock engineering problems though it is still in its infancy stage. The quantity and calibre of the geotechnical datasets influence the technique to be selected for a particular problem, just like in any AI (ML and DL). In terms of which algorithm is most appropriate for generating the predictions, this is contingent upon the expected outcome as well. Various machine language algorithms (MLAs) have been applied to classify rock mass properties, rock bursts, tunnel performance, etc. Mining and tunnelling projects frequently have incomplete datasets due to the expense of field data collecting or laboratory testing. In practice, a simple statistical analysis may be carried out to get conservative estimates of these properties. These estimates can then be scaled up to the properties at the rock mass scale using analytical or empirical methods.

Compared to manual processes, MLAs offer a more accurate way of establishing the correlation between the rock mass scale's and the laboratory scale's attributes, possibly avoiding bias. Using inputs representing physical properties that have been categorized according to the expected severity of the rockbursts or tunnel deformation, algorithms for rockbursts and tunnel performance have been devised. An overview of the MLAs that have been studied for use in rock engineering-related problems include and are not limited to Table 1.

Table 1. Different machine language algorithms that have been used in rock engineering problems

Rock Engineering Problem	MLAs	Opportunities
Rock mass properties	Categorical descriptions ANNs	• Backwards predict rock mass properties based on observed site conditions • Predict rock mass scale properties based on lab-scale properties and rock mass behaviour
Laboratory testing and constitutive behaviour	Numerical measurements ANNs	• Use geology and peak Unconfined Compressive Strength to predict crack initiation and crack damage thresholds • Use laboratory tests and field observations to predict constitutive behaviour
Slope stability	SVM	• Use rock mass scale classification (e.g., Q, RMR) to predict lab-scale properties • Predict slope movements based on geometry, piezometers, inclinometer data, etc.
	Categorical descriptions ANNs	
	SVM, RF, Clustering	• Predict volume of structurally controlled failure based on mapped discontinuities
Point cloud analysis	RF, kNN	• Use successive tunnel scans to get volume differences and predict time-dependent deformations
	Numerical measurements ANNs	• Predict stress/strain fields for input into numerical models • Use preliminary/incomplete field mapping to prediction rock mass classification (e.g., Q, RMR)
Tunnel performance	Categorical descriptions ANNs	• Predict tunnel support class based on rock mass classification (e.g., Q, RMR)
	SVM, RF	• Predict rock support performance-based on geology, excavation method, environmental conditions, etc. • Use microseismic monitoring arrays to predict rock mass deformation as excavation is developed
	Categorical descriptions ANNs	• Predict magnitude and location of events using 3D excavation geometry, time-series seismic events, mapped geology, etc.
Rock bursts	Naïve Bayesian classifiers kNN, RF, SVM, Decision Tree	• Use previous rockburst events, geology, etc. to predict magnitude of failed material and performance of rock support • Use mapped rock classification (e.g., Q, RMR) to predict probability of rockburst
	Categorical descriptions ANNs	• Use blast parameters and damage extent to predict optimum parameters for future blasts
Blasting	Numerical measurements ANNs SVM	• Predict blast parameters using mapped rock classification (e.g., Q, RMR)

Artificial neural networks (ANNs) have been the subject of research to identify rock masses (Sklavounos & Sakellarios, 1995), ascertain strength attributes (Singh *et.al.*, 2001), and simulate stress-strain behaviour (Millar *et. al.*, 2002). Rock mass is an uneven, naturally occurring substance with intrinsic variability and non-uniform qualities, making it challenging to numerically simulate the behaviour of rock masses. Constitutive models and basic equations must represent the geometry and physics of the rock mass. In some instances, these limits understate the complexity of the problem, but data-driven approaches like ANNs can overcome this (Jing & Hudson, 2002). The prediction of rock bursts (Afraei, 2019), defined as an accumulation and abrupt release of strain energy, open-pit stability (Ferentinou & Fakir, 2018), defined as the stability of the mine slope geometry, tunnel convergence (Mahdevvari, 2012), and other phenomena have been studied using ANNs. Several authors have used ANNs successfully in rock engineering projects to model complex behaviour of rock mass over other MLAs.

The primary benefit of ANN's is their ability to overcome the geometrical and physical limitations that control the constitutive behaviour and rockmasses and pose challenges for numerical modelling techniques. This is because the data-driven approach learns from the particular situations it is given to inform future predictions rather than depending on a function to capture all the expected behaviour of rock masses. An additional benefit is that ANN's can replicate the 'perception' that the human brain is capable of, including judgement based on empirical methodologies (Marsland, 2009)

The ANNs can also be helpful in numerical modelling for capturing time dependency. Numerical models may have difficulty simulating the time-dependent behaviour of rock masses (Paraskevopoulou & Diederichs, 2018). However, given that ANNs may accept time-lag variables as input, there might be a chance to combine one with numerical models.

Significant Benefits of Machine Learning in rock engineering and safety

The benefits of MLAs to rock engineering include increased efficiency and accuracy of various processes, safety, reliability, as well as the ability to uncover patterns and relationships in complex data, all while lowering costs (Morgenroth *et al.*, 2019). Overall, ML algorithms significantly enhance the ability to predict, monitor, and manage the various challenges in rock engineering, leading to improved safety and efficiency in mining and civil engineering projects. Here are some key benefits of the MLAs:

- **Enhanced Decision-Making**
 - i. Support for practitioners: It can provide rock engineering practitioners with data-driven insights, improving decision-making in complex and uncertain geological environments.
 - ii. Simulation capabilities: Rock engineering practitioners can simulate various scenarios and assess the impact of different strategies on rock stability and safety, leading to better-preparedness.
- **Predictive Modelling**
 - i. Rock behaviour prediction: ML models can predict the behaviour of rock formations under different stress conditions, aiding in the design of safer and more efficient mining and construction operations.
 - ii. Hazard prediction: It helps predict potential hazards such as rock bursts, fall of grounds, resulting in proactive safety measures.
- **Pattern Recognition and Data Analysis**
 - i. Complex data handling: Rock engineering involves analysing vast amounts of geological data. ML can quickly identify patterns and correlations that might be missed by traditional methods.
 - ii. Anomaly detection: By analysing sensor data, ML can detect anomalies that may indicate the onset of dangerous conditions, enabling early intervention.
- **Optimising of underground designs**
 - i. Material selection: ML can optimise the selection of excavation materials based on the specific conditions of the rock mass, improving the safety and longevity of rock engineering projects.
 - ii. Design efficiency: It helps optimise the design of tunnels, slopes, and foundations by

predicting the most stable configurations under varying geological conditions.

- **Cost Reduction**

- i. Reduced failures: By accurately predicting risks and optimising designs, ML reduces the likelihood of costly failures and accidents.
- ii. Efficient resource allocation: It aids in better allocation of resources by predicting where and when reinforcement or monitoring is most needed.

CONCLUSIONS

ML can assist rock engineers and practitioners to increase the efficiency and use of large data sets in the design process as the field becomes increasingly data-driven. Despite its great potential, the performance of ML algorithms is inextricably linked to the quality and quantity of the geotechnical data available and the fit-for-purpose algorithm chosen. It is crucial to note out that ML algorithms trained on low-quality data can provide inaccurate and highly subjective outcomes.

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Richard Masethe

University of KwaZulu Natal, South Africa

Richard is actively involved in Rock Engineering, Geophysics, and Seismology. He holds a BSc Hons (Geophysics), a GDE (Rock Engineering), an MSc (Rock Engineering), and a PhD (Geophysics and Rock Engineering) from the University of the Witwatersrand. He started his career in 2007 as a graduate rock engineering trainee in Goldfields, and was involved in rock engineering projects and seismology in Sibanye-Stillwater. He is currently a lecturer at the University of KwaZulu Natal, College of Agriculture, Engineering and Science, specialising in research that includes rockburst phenomena, machine learning, artificial intelligence, geophysics, hazards and risks in mining seismology, probabilities, and risks in rock engineering designs.

IMS Hub: Mining houses working together to reduce fatalities with simplified and visualised safety standards

J.C.S. Chipps

Jincom, South Africa

Every year an unacceptable number of miners are injured and killed¹, largely because they do not have access to clear and simple critical controls to be able to do their jobs safely. This challenge is not unique to the mining industry; research has indicated that 66% of migrant workers make mistakes at work because they simply don't understand safety instructions².

Traditionally, safety standards are developed by engineers and subject matter experts who are highly proficient in their respective technical fields, but lack the skills to make content easily understandable and digestible by large and diverse workforces at their operations (people with different levels of experience, literacy levels, languages, etc.)

Other high-risk industries across the globe, facing similar health, safety and environment (HSE) communication challenges, have provided their frontline workers access to simplified and visualised standards and critical controls. They adopt this solution for the following reasons:

1. Our brains are wired to process visuals better than reading through heavy technical text documents. Most information input comes through our eyes with more than 70% of the human body's sensory receptors being in our eyes³. So it makes sense then, when critical content needs to be quickly and effectively understood, communicated and implemented that it should be in a visual format.
2. We process visuals fast. The human brain can process entire images in as little as 13 milliseconds (three times faster than blinking)⁴. It follows that in high-risk situations and environments where critical safety information needs to be communicated quickly and effectively, visual content is king.
3. Visuals are more memorable. Our brains remember in pictures. If we hear a piece of information, it's likely that after three days we'll struggle to recall it and may only retain 10% of that content. But if an image is added to the information, we will recall up to 65% of it⁵. Using visuals to convey critical safety material boosts memory retention so it makes sense then to adopt a visual safety management strategy.
4. Visual content reduces literacy and language barriers. Regardless of the language you speak, you can understand visual representations.
5. Visuals aid the actual understanding of the content. (Imagine having to assemble a Lego set or Ikea furniture without the clear visual guides!).

¹ ICMM (2024). News and Analysis. Safety Performance: Benchmarking Progress of ICMM Company Members in 2023. Available from: <https://www.icmm.com/en-gb/research/health-safety/benchmarking-2023-safety-data>

² Trajkovski, S., Loosemore, M. (2006). *Safety implications of low-English proficiency among migrant construction site operatives*. International Journal of Project Management.

³ Marieb, E.N., Hoehn, K. (2007). *Human Anatomy & Physiology*. Benjamin Cummings.

⁴ MIT (2024). News Office. In the blink of an eye. Available from: <https://news.mit.edu/2014/in-the-blink-of-an-eye-0116>

⁵ Medina, J. (2008). *Brain Rules*. Pear Press

Developing quality, simplified and visual HSE content requires considerable time and effort from an HSE team as well as a budget investment. Some mining companies are following the approach of using simplified and visualised content, however they all started independently making investments into simplified and visualised content, essentially ‘recreating the wheel’, and therefore infinitely duplicating the mining industry’s efforts to tackle the same issues.

This is where the International Mining Safety (IMS) Hub filled a massive need in the industry. IMS Hub founding partners, which include African Rainbow Minerals, Anglo American, AngloGold Ashanti, Eramet, Gold Fields, Harmony, Impala, Ma’aden, Sibanye-Stillwater, Teck Resources, Vale and the Minerals Council South Africa, all came together to address this challenge and achieve the common goal of reducing fatalities and serious incidents in mining. Together, these partners developed a ‘by-industry for-industry’ library of 300+ global best-practice and industry-endorsed, simplified and visualised health and safety standards, critical control checklists, toolbox talks, key message posters and incident learnings, covering over 70 fatal hazards.



Figure 1. Example of pages from simplified and visualised standard for Confined Spaces on the IMS Hub.

Each founding partner contributed two or more suites of materials around key fatal or catastrophic risks at their operations. Once transformed into simplified visual tools, they then shared the content on the Hub for the use and adaptation by all other partners.

The IMS Hub is an example of leaders in mining coming together to share and learn from one another for the benefit of reducing fatalities and serious incidents in mining across the globe.



Jonathan Chipps

Managing Director
Jincom

Jonathan Chipps is a seasoned professional with 17 years of experience in the content and communications industry. As the Managing Director of Jincom, which specializes in frontline workforce engagement within high-risk sectors. Over the past five years, Jonathan has collaborated with some of the world’s largest mining companies, focusing on enhancing safety performance. His passion lies in delivering practical solutions that empower diverse workforces to understand and execute their jobs safely through simplified, visualised, and digitised health, safety, and environment (HSE) content. Jonathan is dedicated to driving positive change in safety culture across industries.

Climate change and workplace health in south africa: emerging hazards and mitigation strategies

M. Janse van Rensburg

Mine Ventilation Society of South Africa
South African Institute of Occupational Hygiene, South Africa

BACKGROUND

Climate change poses significant global and workplace health risks, driven by rising temperatures, shifting weather patterns, and an increase in extreme events. These changes disrupt environmental, social, and economic systems, intensifying occupational health hazards. The World Health Organisation¹ warns that over 3.6 billion people are at heightened risk due to climate change, with an estimated 250,000 additional deaths annually from heat stress and other related complications over the next decade. These environmental shifts directly affect workplace conditions, particularly through extreme temperature fluctuations. One of the primary impacts of climate change in the workplace is exposure to temperature extremes, which can cause serious health issues such as heat stress, heat stroke, and fatigue. Prolonged exposure to excessive heat reduces productivity and increases the risk of heat-related complications like sunburn and sleeplessness. Additionally, climate change affects the ozone layer, which reduces protection from harmful UV radiation. Workers in areas with significant ozone depletion face a higher risk of developing skin cancers, eye damage, and weakened immunity. Climate change also increases the frequency and severity of natural disasters, such as floods, landslides, and wildfires, which pose direct physical and psychological health risks to workers. These disasters heighten the risk of injuries, mental health issues, and accidents in the workplace, particularly for outdoor workers. In South Africa, workplace health hazards from extreme heat, air pollution, and UV radiation remain high. This underscores the need for stronger Occupational Safety and Health policies, including better protective gear, and comprehensive risk assessment and mitigation strategies to address the growing impacts of climate change on workers.

Methodology

The study utilised a systematic review approach to explore the relationship between climate change and workplace health in South Africa, focusing on emerging hazards and mitigation strategies. This method was chosen for its ability to provide a comprehensive analysis of existing evidence and identify gaps for future research. The review involved online searches using platforms like Google, Google Scholar, and PubMed, targeting peer-reviewed articles, original research, and grey literature from organisations such as the ILO and WHO. Search terms included combinations of "climate change," "health impacts," and "workplace health" in South Africa. Boolean operators ("OR" and "AND") were used to refine the search. Inclusion and exclusion criteria helped to filter and select the relevant articles.

Results

The review highlights that climate change poses significant workplace health hazards in South Africa, with about 60% of the studies focusing on this region. Extreme temperatures, ultraviolet (UV) radiation, air pollution, and natural disasters are identified as major threats to workers' health. Notably, 65% of the studies reported adverse effects such as heatstroke and exhaustion due to rising temperatures. Wright & Norwal (2021) link heat-related fatalities in the North-West and Northern Cape Provinces to climate-induced temperature increases, while Scovronick et al. (2018) attribute a portion of deaths between 1997 and 2013 to similar causes. Levi et al. (2018) suggest that heat action plans could effectively reduce mortality, underscoring the need for robust climate mitigation strategies in the workplace.

UV radiation and air pollution are also significant concerns. Increased UV exposure, exacerbated by greenhouse gas emissions and ozone layer depletion poses heightened risks of skin cancer and eye complications, with studies by Grandi et al. (2023); Hooste (2023); Barnes et al. (2023), documenting these effects. Similarly, ambient air pollution, as reported by Chersich et al. (2018) and Wright et al. (2023), is responsible for a considerable number of deaths, primarily from cardiovascular and respiratory diseases. The research indicates that workplace safety protocols must be enhanced to address these pollutants effectively, suggesting that policies such as those proposed by the Air Pollution and Climate Change for Sustainable Development in Africa could prevent a significant number of deaths annually. Furthermore, weather-related natural disasters like floods and landslides present grave risks, with substantial fatalities and displacements reported in provinces like KwaZulu Natal and Eastern Cape. The limited disaster management infrastructure and access to services exacerbate these challenges, highlighting the urgent need for improved organisational and national response strategies. Implementing recommendations from the International Labour Organisation could mitigate some of these effects, emphasising the importance of adaptive measures in safeguarding worker health and safety in the face of climate change. Overall, the studies collectively advocate for intensified safety measures against climate-related hazards in South Africa. The findings emphasise the need for comprehensive strategies that include monitoring and mitigating the impact of heat, UV radiation, and air pollution, alongside preparing for natural disasters to enhance occupational health and safety in the changing climate.

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Monique Janse van Rensburg

Occupational Hygiene Specialist
Affiliation of the Mine Ventilation Society of South Africa
Southern African Institute of Occupational Hygiene

As a dedicated and skilled Occupational Hygiene Professional and registered with MVSSA and SAIOH, and a proven track record in mine health and safety, I bring a wealth of experience and expertise to the table. My journey in the field of occupational hygiene has been marked by substantial contributions to the companies I've worked for, including Vortex Solutions cc, Glencore Tweefontein Colliery, and Siyanda Bakgatla Platinum Mine. Where I am experienced in both Platinum and Coal commodity. I am also the Chairperson for the 2024/2025 MVSSA Northern Branch Committee and previously MVSSA Colliery Branch Committee Newsletter Editor.

Eliminating harm through critical control compliance

O.S.A. McCree

The Compliance Group (Pty) Ltd, South Africa

While having made great strides in reducing the number of fatal incidents, the South African mining industry, a pivotal sector in the nation's economy, remains to face challenges related to safety management, incurring several fatal incidents. The implementation of Critical Control Compliance (CCC) offers a strategic approach to mitigating risks and eliminating harm in mining operations. In this paper we explore the principles and practices of CCC, emphasising its application within the South African mining context.

When considering CCC, we must understand that focus should always be on the potential of an incident as opposed to the actual severity/consequence. While certain hazards/energy will typically have several controls in place, these controls may be cumbersome or difficult to implement or understand by the crew. In these instances, it is key to identify which of the existing controls significantly reduce the potential as well as the severity of the consequence (both sides of the bowtie analysis). It is these controls that we need to focus on or develop if they do not exist, and make sure they are simple to understand at all levels, implement and also monitored via line management. These monitoring systems should focus on the continual momentum of these controls, as well as the efficacy in reaching the intended result.

The outcome of this paper suggests that a robust CCC framework, coupled with continuous monitoring and stakeholder engagement, can significantly advance harm reduction efforts in the industry.

INTRODUCTION

Over the past three decades, the mining industry has made significant progress in reducing workplace fatalities, driven by advancements in technology, enhanced safety protocols, and a heightened focus on health and safety standards. These improvements have led to a considerable decrease in incidents across the sector. However, in recent years, the industry appears to have encountered a proverbial 'glass ceiling' in its efforts to completely eradicate fatalities and serious injuries.

Despite the success of conventional safety measures in addressing more frequent, lower-severity incidents, they often fall short in managing the complex and systemic risks that give rise to less frequent, yet fatal and multi-fatality events. As a result, the industry is finding it increasingly difficult to transition from incremental gains to a truly zero-harm environment.

Breaking through this barrier requires a paradigm shift in approach – moving beyond traditional safety measures and intensifying the focus on critical control management. This entails not only the accurate identification and development of critical controls but also their effective implementation, strict compliance, and continuous monitoring to ensure desired outcomes. Furthermore, addressing the human, engineering, systemic, and organisational factors that contribute to high-risk events is essential.

Only by embracing innovative thinking and maintaining a disciplined adherence to these principles, from the strategic level to on-the-ground operations, can the industry overcome the current stagnation and achieve its goal of eliminating harm in the workplace.

Importance of Safety Governance

Safety governance in the mining industry has undergone significant enhancement over the years, shaped by lessons learned from incidents, high-potential incidents, and fatal events, as well as revised legislation and industry best practices. These learnings have been integrated into existing safety frameworks or have driven the development of new safety governance measures. This framework encompassing standards, procedures, protocols, inspections, guidelines, and codes of practice, is grounded in a thorough identification of hazards and associated risks, as determined through baseline and issue-based risk assessments. Such a risk-based approach is now deeply embedded in the industry's safety management culture.

The core objective of safety governance is to prescribe how tasks should be performed safely and without incident. It takes into account inputs from risk assessments, legal requirements, industry best practices, and the collective experience of representatives appointed to safety and standards committees typically found at mine sites. Modern safety standards and procedures reflect a dual approach: integrating elements of both traditional 'safety management systems' which focus on worker safety, injury prevention, safe work practices, and 'process safety management', which is centred on safeguarding systems and processes, preventing catastrophic failures, and managing risks associated with hazardous operations, processes, activities and tasks. A lack of clear understanding of the distinction between these two approaches has often resulted in their combined content in contemporary safety standards and procedures.

Once safety governance is established, its implementation is achieved through the integration of the governance into training material, programmes, and competency assessments, followed by awareness campaigns, communication, on the job coaching etc. The workforce is provided with access to the relevant governance, and compliance is monitored through various mechanisms such as inspections, audits, and task observations.

For mine management, tracking compliance with safety governance is critical in ensuring that operations are conducted safely, that employees are working in a safe environment, and that non-compliance is appropriately addressed. This oversight not only ensures the safety of the workforce but also provides assurance to shareholders and regulatory authorities, helping to maintain the mine's licence to operate and protect its social licence within the community.

Critical Control Management and subsequent Critical Control Compliance as a Safety Strategy

The safety strategy of a mining operation is designed to articulate how safety will be managed at the highest organisational level. Drawing a parallel with Sun Tzu's *The Art of War* (2005), the distinction between strategy and tactics is analogous to strategy defining the overarching plan, while tactics represent the actions taken on the ground to execute that plan. In a mining context, one could consider the 'bank' area, where personnel enter the underground workings, as the metaphorical border. Thus, the safety strategy culminates at the bank, and beyond this point, the approach must shift to tactical execution.

Typically, a mine's safety strategy outlines a vision, mission, and objectives, often structured around key focus areas such as 'culture', 'systems and processes', 'enabling environment', 'leadership', etc., which serve as pillars supported by typical foundational elements such as 'operational discipline', 'culture', etc. However, Critical Control Management (CCM) and Critical Control Compliance (CCC) rarely features prominently as a central component of these safety strategies. While elements of CCM may be embedded within the broader 'risk management system' through mechanisms like 'control self-assessments' or operator-led checklists featuring critical checks in the continuous risk assessments level, the CCM system is seldom positioned as a primary means of addressing significant risks, such as Material Unwanted Events (MUEs) or Significant Unwanted Events (SUEs).

By adopting a more deliberate approach, the CCC process, as recommended by the International Council on Mining and Metals (ICMM), can be mapped into distinct strategic and tactical steps. This differentiation clarifies roles and responsibilities for both the implementation and monitoring of critical controls, ensuring that accountability for making the system work is better understood. In this framework, strategic steps establish the high-level objectives and guidelines, while tactical steps focus on the practical application of these principles to effectively manage and mitigate the most significant risks faced by the operation.

The difference between ‘Fatal Risk Control Protocols’ and CCC

The Fatal Risk Control Protocols (FRCP) have been developed and implemented across the mining industry to address the risks associated with hazards that have historically resulted in fatalities. These protocols provide comprehensive requirements for personnel, machinery, equipment, and systems. However, FRCPs often result in a hybrid of awareness initiatives and compliance mandates related to existing procedural and regulatory standards. Their primary objective is to focus attention on significant hazards, ensuring that the workforce remains cognisant of the necessary actions to effectively manage these risks.

CCM serves as a systematic approach in which the FRCP is integrated into a broader decision-making framework involving a collaborative team that includes individuals from management to operational levels. This process is designed to evaluate which specific requirements and controls are essential for preventing incidents. Essentially, CCM distills the FRCP down to the most critical controls that are necessary to mitigate risks and enhance safety outcomes within the mining environment.

The ICMM framework on Critical Control Management

Key principles and steps of Critical Control Compliance

The ICMM published an Implementation Guide in 2015 (ICMM 2015) which contains information as to the process of CCM. Based on my experience within the mining industry, I have observed that the most significant challenges for mines typically arise in Steps 03, 04, and 05 of the CCM framework, as illustrated in Figure 1 below.

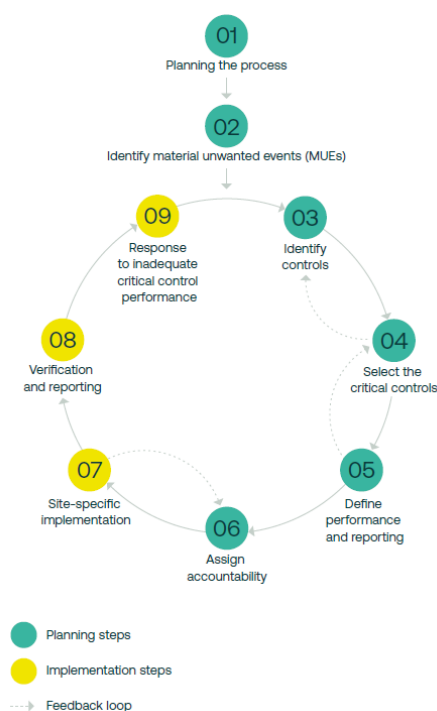


Figure 1. The CCM process by the ICMM.

Why we struggle with step 03 – Identify Controls

As previously mentioned in this paper, current baseline risk assessment models, approaches, and templates typically identify controls as ‘procedures,’ ‘supervision,’ ‘training,’ and similar categories. However, many mining operations have yet to fully embrace the benefits of the bowtie analysis methodology. Among those that do, there is often a limited understanding of the process, leading to the use of tools such as Microsoft PowerPoint, Word, or Excel to conduct bowtie analyses, without a supporting risk and mitigation database to maintain the integrity of the risk management system.

A comprehensive bowtie software platform effectively integrates all risk and mitigation data associated with specific processes, activities, and tasks. This platform enables cross-referencing of systems, ensuring that an up-to-date baseline and risk register remain dynamic and relevant. In the absence of a dedicated bowtie platform, it becomes challenging to accurately identify and manage specific controls effectively.

Why we struggle with step 04 – Select the Critical Controls

Because of the accepted approach in the conventional baseline risk assessments to list controls as ‘procedures,’ ‘supervision,’ ‘training,’ etc., we are unable as a team to identify a critical control without having to open the procedure/s we have implied in the baseline and read through them, look at the training material and be able to identify steps or activities which may be critical controls. In addition, our representation at standards committees is not always cross-functional and/or a vertical slice of representatives and could have biased views on controls due to lack of experience of the specific tasks.

Why we struggle with step 05 – Define Performance and Reporting

As part of the continuous risk assessment process, operations are inundated with various checklists, safe declarations, permits, and forms that require daily completion. To streamline this administrative burden, some mines have adopted software solutions such as Optical Character Recognition, which allows for the scanning of forms to generate real-time results and reduce the analytical workload.

However, the current teams tasked with the CCC programme often struggle to determine which checklists and protocols need to be developed in a manner that avoids redundancy with existing measurements. There is also a concern about introducing additional ‘noise,’ meaning that the increased volume of analysis could demand more time and resources without adding value.

In essence, I believe that the personnel assigned to the CCC programme lack sufficient experience in the process to effectively develop these criteria. Furthermore, they do not possess the authority to eliminate unnecessary duplication or ‘noise’ from the system.

Implementation in South African mines

While mining operations are beginning to grasp the processes and efforts necessary to effectively implement a CCM programme, discussions regarding cost sensitivity remain inherent to the nature of business. However, a critical success factor for the CCM programme is the allocation of dedicated resources to manage it effectively. This programme should not become an additional burden or portfolio for existing Standards Committee members, safety officers, and similar roles. While these individuals must be integral to the programme, they cannot successfully manage the CCM initiative alongside their broader operational responsibilities.

There is a growing acceptance of the bowtie analysis concept within the industry. Some mines have invested in comprehensive software platforms that integrate with their existing baseline risk assessment processes, while others continue to utilise detached bowtie diagrams created in standard applications such as Microsoft PowerPoint, Word, or Visio. Although these tools may facilitate the identification of controls, they often lack integration with the dynamic baseline risk management processes.

In my consulting experience within the industry, there remains a significant need for further education on the CCM programme. This education should focus on identifying the appropriate personnel to lead the initiative and providing training based on the guidance and materials from the ICMM.

The ICMM notes on its webpage, "Protecting workers and local communities through effective critical control management" (ICMM, 2021), that the COVID-19 pandemic prompted rapid identification, development, and effective implementation of critical controls to mitigate the spread of the virus. Where operations demonstrated a high level of adherence to these controls, the impact of the virus was significantly reduced. This raises the question: why did personnel respond so effectively to the implementation and sustained compliance with these controls?

In my view, the answer lies in the immediate nature of the threat posed by the pandemic, akin to a safety incident that can occur suddenly, in contrast to an environmental incident where the consequences may unfold over many years, often beyond the tenure of the current workforce in that area. People tend to respond more readily to perceived immediate threats. The ICMM's research supports this perspective, revealing several key findings:

- Individuals are motivated to take action when they perceive and understand a hazard as a real and immediate threat.
- The pervasive nature of COVID-19 created a sense of urgency that was amplified by strong leadership support.
- The pandemic became the primary focus for leadership, driving collective efforts to address the hazard despite the complexities involved. This united commitment was evident at all organisational levels, from executives to operators.
- Furthermore, clear, consistent, and straightforward communication flowed from executives to operators, ensuring that everyone understood and conveyed the same message, minimising the potential for information loss in translation. Messaging was direct, actionable, and implementation strategies were executed uniformly, with monitoring conducted with integrity and responsiveness, facilitating timely feedback for further action.

Adapting safety models for the mining industry

Once a mine begins to implement the CCC programme and engages in its baseline risk assessments and mitigation processes, the merits of a process safety management approach become increasingly evident. In some operations, this approach is gaining traction as a complementary strategy to traditional systems, enabling a comprehensive understanding and mitigation of risks throughout the engineering process. The hierarchy of controls evolves into an active component of this process, rather than merely serving as a classification tool for existing controls. Along with the systemic and transactional safety processes, we are also faced with what may be the biggest challenge in safety management – the humanistic element and behaviour.

Historically, various behaviour-based programs and initiatives have established a foundational premise that between 80% and 90% of incidents are attributable to at-risk behaviour. However, based on my professional experience—having investigated over 200 injuries, 80 high-potential incidents, and 50 fatalities—I believe this statistic should be adjusted to reflect that 99% of incidents can be linked to human behaviour, with the remaining 1% attributed to 'acts of God.' When we assert that 80% to 90% of incidents result from at-risk behaviour, we imply that the remaining incidents (excluding the 1% for acts of God) are condition-based. Yet, it is crucial to investigate how these conditions came about in the first place.

For instance, the act of installing a return snatch block for a winch using a single eyebolt may not yield immediate consequences, but it sets the stage for potential incidents. Similarly, ground falls caused by improper support spacing are conditions that arise from behaviour. This pattern extends to various factors, including the demarcation of geological features and the failure to manage water influx into ore passes. Throughout my investigations, I have rarely encountered cases where employees lacked awareness of the applicable standards, procedures, or associated risks. Therefore, our focus should shift toward fewer but more effective controls that are manageable and stem from a genuine understanding of the associated dangers, rather than creating unnecessary 'noise' within our systems.

The CCM programme aims to prioritise the prevention of high-potential incidents with severe consequences over the more frequent, low-severity incidents that occur daily in the industry. For example, when addressing a fall of ground (FOG) in a workplace, the response to reporting and investigation is typically triggered by the severity of the potential consequences. In contrast, first aid cases (FAC) or medical treatment cases (MTC) often receive minimal investigation. Although some mines recognise the importance of focusing on potential incidents rather than solely on actual occurrences, the quality and thoroughness of these investigations do not always align with those conducted for more severe incidents.

In the case of a FOG where no injuries occur, it is classified as an incident. A nearby individual may experience a 'near miss' while being even closer could result in a FAC, MTC, lost time injury, or reportable incident. The severity of the outcome can shift dramatically within a matter of centimetres. This underscores the necessity of establishing triggers based on potential outcomes rather than solely on actual consequences. While numerous controls are in place to manage everyday hazards and risks, the CCC programme is specifically designed to eliminate the potential for high-consequence events.

Risk-Based Approaches for CCM

The conventional risk-based approach in the mining industry typically begins with a baseline risk assessment focused on operational processes, activities, and tasks. This assessment is conducted by a cross-functional team of personnel who identify high-level hazards and risks, ranking them according to various matrices that consider both inherent and residual probabilities and consequences/severity after controls have been implemented. The outcome of this baseline risk assessment is often a profile that categorises processes, activities, and tasks as critical, high, medium, or low risk. Critical and high-risk areas are subsequently subjected to more detailed issue-based risk assessments. The third level of this approach involves continuous risk assessment, which encompasses the use of checklists, permits, inspections, and other tools that effectively become controls themselves, rather than merely serving as additional layers of assessment.

While this methodology has proven effective in the past, I believe that the traditional format of baseline and issue-based risk assessments—whether conducted in Microsoft Excel or through specialised software—may not provide the optimal inputs necessary for identifying critical controls. Such assessments primarily highlight MUE and SUE relevant to the operation.

Through interviews, discussions, and consultations with various companies that have successfully implemented the CCM process, I have observed that the bowtie analysis methodology, as advocated by the ICM, possesses a unique capability to map controls both pre- and post-incident when integrated with a process safety management approach. This allows a competent and experienced team to effectively identify critical controls. In conventional baseline risk assessments, controls are often categorised according to the hierarchy of control and are listed as supervision, procedures, training, communication, etc. In contrast, bowtie analysis requires that specific controls be identified and evaluated, promoting a level of detail that fosters new insights and discussions among team members as they work to pinpoint controls that could prevent incidents or significantly reduce their likelihood.

When consulting on the identification of critical components or controls, I often use the analogy of a highlighter. The purpose of a highlighter is to emphasise specific portions of a page for the reader's attention; however, if the entire page is highlighted, no particular part stands out. Similarly, each control listed in conventional baseline risk assessments must be thoroughly examined and deconstructed to ascertain where the greatest effectiveness lies in preventing incidents.

Proactive vs. Reactive Safety Measures

The bowtie analysis conducted on MUE/SUE provides controls both on a preventive side, as well as a mitigative side post-incident in order to lessen the impact/consequence of the incident. In this instance of CCM, our focus needs to be on the pre-incident controls.

Case Studies in Critical Control Implementation

Success Stories: Harm Elimination through Effective Controls

The ICMM indicate in a publication (ICMM 2019), that there has been significant improvement in the fatality rates across its members since the inception of the CCM programme.

Table I: All data for ICMM company members in 2019

Year	Total recordable fatalities (TRF)	Fatality frequency rate ²	Total recordable injuries (TRI)	TRI frequency rate ²	Total hours worked
2019	287	0.118	7,771	3.20	2,432,053,536
2018	50	0.022	7,751	3.41	2,275,510,188
2017	51	0.027	7,515	3.94	1,906,708,433
2016	63	0.032	8,445	4.26	1,981,148,588
2015	60	0.027	10,494	4.70	2,231,437,832
2014	56	0.024	10,455	4.50	2,324,525,784
2013	91	0.035	11,636	4.52	2,571,500,557
2012	90	0.033	13,895	5.07	2,738,579,590

A case study and benchmarking with Thungela Mine, demonstrated a clear process and the efficacy of the bowtie process with a MUE/SUE as identified by a conventional baseline risk assessment, subsequently being processed through a bowtie analysis software platform in Figure 1. The barriers and escalation factors are identified, and the team discusses these in detail to determine which are critical controls. It is reported by management of Thungela that within these discussions lies the true value of the process, where debate and discussion on the controls are had and the efficacy of controls are done.

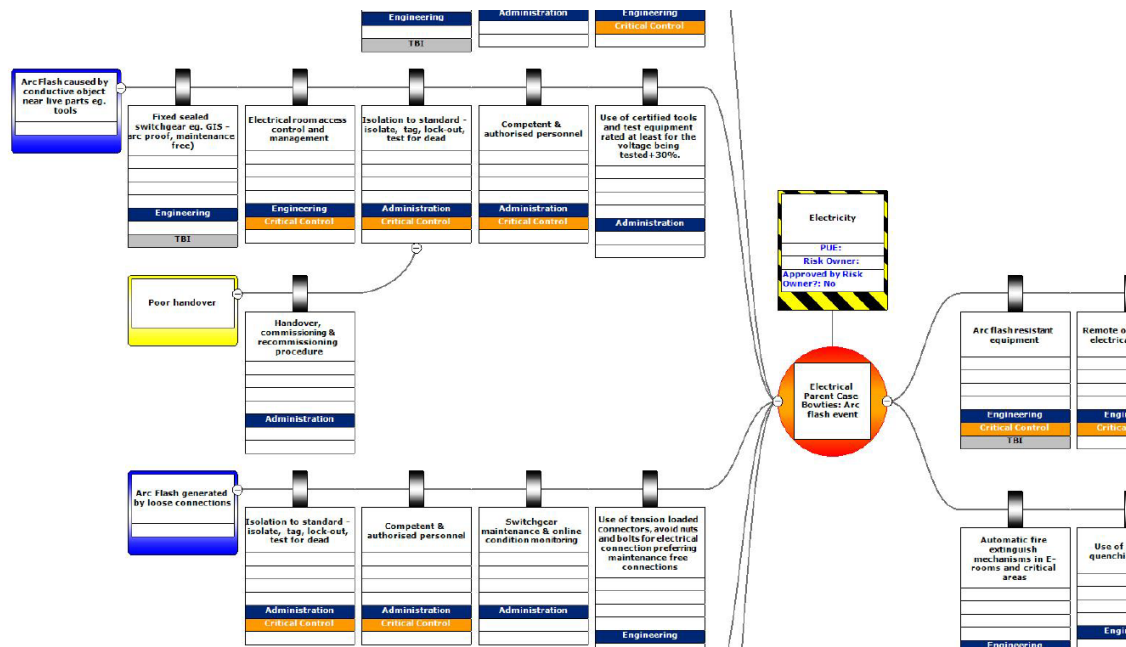


Figure 1. An example of an identified MUE /SUE going through the bowtie process.
Level based information.

While converting strategy into tactics, it may be challenging to get a consistent message across to all levels of employees from executives down to operator level, with the message often getting lost in complexities, forms and checklists, talk topics, campaigns etc. In essence, I have come to believe in the following example for level-based and level-appropriate information:

While we can list all governance, training and awareness material regarding winches and rigging, the following should be the information a winch operator must have:

- This is my winch (fostering ownership)
- This is how this winch and its components (including scrapers, ropes, snatchblocks, etc.) can injure me.
- This is how this winch and its components (including scrapers, ropes, snatchblocks, etc.) can injure my colleagues.
- This is how I prevent an incident involving my winch and its components.

The winch operator does not need the legislation regarding winches, procedures, FRCP or best practice manuals with them or at the winch. The training and continuous risk assessment forms should ensure that the information above is at the forefront of the operator's mind. The higher we go in the supervisory and managerial hierarchy, the more information becomes relevant to each level, where the shift supervisor for example needs to be well versed in the procedure and the FRCP requirements.

When considering this level-based information while drafting critical control implementation tactics, the ambiguity in what needs to be done and how, must be eliminated and the message needs to be the same from executive to operator. The instructions regarding critical controls as well as the questions asked on forms and checklists during monitoring must be articulated in the same simple way at all levels. These levels must have the same understanding of what is required and must be able to explain and demonstrate it in exactly the same way. By arriving at this point, we can be sure that the control we have identified and deemed a critical control is simple, easily understood and executable verbatim.

CONCLUSION

The successful implementation of a CCM programme within the South African mining industry marks a pivotal milestone in its ongoing efforts to enhance safety and operational integrity. By systematically identifying, verifying, and rigorously managing critical controls, the industry has demonstrated its capacity to mitigate the most severe risks that have historically contributed to fatal and high-consequence incidents. This targeted approach enables a shift from reactive measures to proactive risk management, ensuring that critical controls are in place, functioning effectively, and continuously monitored.

Incorporating the CCM framework has strengthened the industry's safety culture, embedding a deeper understanding of risk across all levels of operation. This has not only contributed to a measurable reduction in harm but has also fostered greater accountability and resilience in managing complex mining hazards. Moreover, the alignment with global best practices positions the South African mining sector as a leader in safety innovation and risk management.

However, the journey does not end with the initial success. The dynamic nature of mining operations, coupled with evolving regulatory requirements, necessitates a commitment to continuous improvement. Ensuring that critical controls remain relevant, adaptable, and effective is essential to maintaining momentum toward the ultimate goal of eliminating fatalities and serious injuries. In this context, ongoing investment in training, technology, and stakeholder engagement will be crucial.

Looking ahead, the CCM framework will continue to serve as a cornerstone for achieving a zero-harm mining environment. Its successful implementation underscores the potential for long-term

sustainability and reinforces South Africa's leadership role in fostering a responsible, safe, and globally competitive mining industry.

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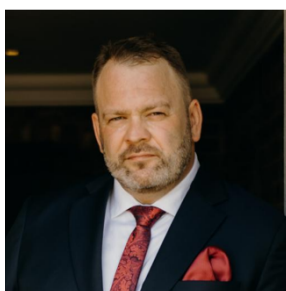
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Thungela Mine Safety Management System (October)



Owen S.A Mc Cree

Managing Director
The Compliance Group (Pty) Ltd

Owen started his mining career in 1999 as a Learner Official at Anglo Platinum Rustenburg section. Working himself up through the ranks with various achievements, he progressed from production, through mineral resource management to the health and safety portfolio.

In this portfolio, he similarly worked his way up the ranks to Manager Group Safety at Lonmin before he started consulting in 2013. During his consulting career he has worked with large corporates in South Africa such as Anglo, Lonmin, Implats, South Deep, Harmony, Vedanta, Glencore Australia, Fluor SA, Sibanye, Multotec SA to name a few, as well as international clients such as African Chrome Fields and Adriatic Metals.

Owen has vast experience and has been widely commended in the safety management domain, in terms of system and resource architecture, culture programs, strategy facilitation, software mapping etc., coaching and development, and specialising in fatal and HPI investigations, having recently completed his 51st fatal investigation since 2013.

Owen is a Chartered Member and annual VIP speaker of the South African Institute for Occupational Safety and Health (SAIOSH) where he also serves as a member for the Legislative Review Committee, as well as the Past President of the Association for Mine Safety Professionals of South Africa (AMSPSA).

A look at reducing the environmental impact of mining and metallurgical processes by employing circular economy principles and the challenges of implementation

H. Booysen¹ and H. Grobler²

¹Samancor, South Africa

²University of Johannesburg, South Africa

Circular economy is not an entirely new concept to the mining and metallurgical industry, as at the site levels the efforts to reduce the negative impacts of extraction and production have been in place for years and make good business sense. Mining and metallurgical processes are essential for resource extraction but often have significant environmental impacts, including pollution, resource depletion, and ecosystem degradation. In response, the mining and metallurgy industries have made concerted efforts to move towards a more sustainable way of working by implementing integrated circular economy principles, such as waste management, optimised resource use and improved product value. The efforts have focused on developing innovative technologies to provide sustainable solutions, emphasising the sustainable use of materials through the entire lifecycle – from extraction to production to disposal. All these efforts aim to work towards a net zero nature-positive world. However, despite its potential, the implementation of these principles faces challenges. These include technological limitations, high initial costs, financing, regulatory barriers, and the need for industry-wide collaboration. Furthermore, the transition from traditional linear models to circular systems requires a shift in mindset, both within industry and among stakeholders, alongside the development of supportive policies and infrastructure.

This paper explores how circular economy strategies, such as closed-loop production, sustainable material sourcing and replacements, and innovative recycling technologies, can be applied in mining and metallurgy to reduce waste, lower energy consumption, and mitigate environmental damage. The case study of slag generation, commercial use and marketing initiatives investigated, and legislative steps taken to have slag approved as a beneficial waste will be the focus of this paper.

BACKGROUND

Population expansion, social awareness and the drive for clean energy technologies are increasing the demand for minerals and metals. Even though mining and metallurgical processes are familiar with the circular economy, to be truly circular more innovation is required.

According to (Gladek, 2019) “we can only define a circular economy if we look to the end state that we want to achieve.” Achieving this requires us to look at the seven pillars of the circular economy:

1. Materials are ‘cycled at continuous high value’ with ‘scarce materials preferentially cycled at shorter intervals so they can be recovered sooner for reuse.’ Ideally materials should be transported in ‘as small a geographic range as possible’. In the case of aggregates, it is supposed that natural materials are used ‘only when necessary’. Slag can be used for this purpose to replace the use of natural materials.

2. All energy is based on renewable sources. In the case of slag-based aggregate, energy is conserved in mining, smelting, and crushing.
3. Biodiversity is supported and enhanced through human activity. Land used for waste filling and dumping of slag should be managed so as not to encroach upon other human activities and assist in preserving ecological diversity which is 'one of the core sources of resilience for the biosphere'. The use of slag reduces the need to find land on which to dispose of it, thereby freeing up land to allow for positive biodiversity impacts.
4. Human society and culture are preserved. 'In a circular economy, processes and organisations make use of appropriate governance and management models, and ensure they reflect the needs of affected stakeholders.'
5. The health and wellbeing of humans and other species are structurally supported through the reduction, control and removal of toxic and hazardous substances. Economic activities never threaten human health or well-being in a circular economy. Slag use has provided an area for job creation.
6. Human activities maximise the generation of societal value. Natural resources are finite and should be preserved and used in a sustainable manner. The recycling of waste materials contributes to this tenet of the circular economy. Slag is an option to use vs the use of quarry stone which is a natural resource.
7. Water resources are extracted and cycled sustainably. Waste dumps and landfill sites are normally placed in areas where water resources are impacted as little as possible, however the reduction of landfill areas will contribute to better land use practices.

Samancor Chrome is a prominent player in the international ferro alloy industry; we are a progressive, innovative company, making a significant contribution to the South African economy and mining sector. Our product ferrochrome is an essential ingredient for the production of stainless steel and is an alloy of iron and chromium with a chromium content of between 50 and 55%. Stainless steel depends on chrome for its appearance and its resistance to corrosion.

The ferrochrome smelting process uses chrome ore, reductants and fluxes to produce ferrochrome alloy. Ferrochrome slag is a waste produced from the production process, generating approximately 1.1-1.6 t slag / t FeCr depending on feed materials. This waste product contributes to the significant volume placed in landfill facilities used for waste disposal. Studies conducted (Ferro Alloy Producers Association, 2013) (van Niekerk, 2011); (van Niekerk, 2015) indicates that this granular waste product is chemically stable and can be used for many activities, but mainly as an aggregate.

Aggregates are used for composite materials such as concrete and asphalt, adding strength and reinforcement to the composite material. Aggregates are used in construction, road (asphalt), precast concrete, drainage and sub-bases. Aggregate mining is very common but requires resources and is dependent on a finite amount of natural reserves to meet the increasing demand for construction materials worldwide.

Aggregate material can be sourced from other processes such as building demolition and recycled to be used as aggregate for construction purposes. "The use of recycled aggregates provides an opportunity for the construction industry to build sustainably." (Hughes, 2024). In addition to contributing to a circular economy through the principles of 'Reduce, Reuse and Recycle' the recycling of slag produced by the ferrochrome industry as aggregates has the advantage of repurposing waste materials for a new application, reducing the footprint of slag dumps and landfill sites and contributing to rehabilitation of land for other uses.

CASE STUDY

The case study looked at the slag generation volumes and management of the slag to determine how this has affected the land use capabilities following the approval of slag as a beneficial waste from 2019, commercial use and marketing initiatives leading towards job creation and the use of a waste as a green

product, and legislative steps taken to have slag classified and approved as a beneficial waste.

SUMMARY OF RESULTS

The use of ferrochrome slag as an alternative and responsible source of aggregates for the construction industry contributes to the reduction of landfill volumes, protecting natural resources and provides a renewable alternative to natural aggregate supplies. The use of slag as an aggregate can contribute to job creation and infrastructure development (Ferro Alloy Producers Association, 2013). The change in legislation by The Department of Environmental Affairs (DEA, now known as the Department of Forestry, Fisheries and the Environment DFFE) allowed for the publishing of the “National Norms and Standards for the Assessment of Waste for Landfill Disposal (“Norms and Standards”), under section 7(1)(c) of the National Environmental Management: Waste Act, 2008 (Act No 59 of 2008), No R. 635 in Government Gazette No 36784, 23 August 2013.”, the classification of “Leachable concentration threshold (LCT) limits and total concentration threshold limits (TCT) for metal ions and anions” which resulted in ferrochrome slags been classified as inert waste “Type 4 waste” (van Niekerk, 2015). Added to this the publishing of the Waste Exclusion Regulations, 2018, read with sections 72 and 73 of the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008), allowed for the slag to be registered as a beneficial waste.

This approval was published in the public domain, providing assurance that slag can be used and assisting in establishing companies to process slag for sale for the various approved uses. It has been allowed to provide slag to consumers as a beneficial waste; the amount of slag disposed of to land has reduced by 58% over a five-year period, thereby reducing land use by approximately 20 hectares. Therefore in order for a true circular economy to be in place, all actions should be measured against equitability, transparency and resilience (Gladek, 2019). Slag as an alternative to natural aggregate provides affordable and abundant resources of material that can be upcycled while at the same time reducing landfill and slag dump sizes, freeing up land to be developed for more sustainable use. The nature of ferrochrome production will continue to renew the resource with slag materials obtained from the melting process.

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Roux Meyer

SHEQ Superintendent - Environment
Samancor Chrome

Roux Meyer has 24 years of experience in environmental management related to mining, smelting and the refinery industry. Land, air, water and waste management are the foundations of his experience. Roux has worked for the following companies in an environmental related role:

- BHP Billiton - Ingwe Colliery Ltd - Mine Closure Operations (Duvha)
- BHP Billiton - Optimum Colliery (Hendrina)
- Xstrata - Mount Isa Mines (Qld - Mount Isa)
- Glencore - Oaky Creek Coal (Qld - Emerald)
- Korea Zinc - Zinc Refinery (Qld - Townsville)
- Glencore - Clermont Coal (Qld - Clermont)
- Samancor Chrome Corporate (Sandton)

Developing an automated system for analysing regulatory paperwork, permits, and compliance reports to ensure adherence to MHSA requirements in mining

K.B. Mwamba and N. Ndiweni

University of Johannesburg, South Africa

INTRODUCTION AND BACKGROUND

The mining industry is one of the essential pillars of the South African economy, contributing significantly to national income, employment, and exports. Rich in resources such as gold, platinum, diamonds, and coal, South Africa's mining sector has historically driven industrial development and sustained economic growth. However, the industry faces challenges in complying with health, safety, and environmental regulations set by the Department of Mineral Resources and Energy (DMRE). These challenges include delays in issuing permits, such as Sunday Labour permissions and Section 54 of the Mine Health and Safety Act (Act 29 of 1996) (MHSA) upliftment. Compliance with these regulations is necessary to ensure worker health and safety, environmental protection, and sustainable mining.

Traditional oversight methods by the mining industry regulator, such as frequent inspections, manual data collection, and post-accident reporting, have been adequate to some extent. However, they also have significant limitations. These include errors in routine compliance reports such as legal appointments, incidents/accident reports, and manually completed quarterly, annual reports, and labour statistical returns, which can lead to severe problems, including legal penalties, regulatory restrictions, adverse health and safety, and environmental impacts. These limitations underscore the need for a more efficient and real-time monitoring system.

Recent technological advancements have revolutionised the approach to compliance in this high-risk sector. Imagine a system consolidating legal documents, permits, and compliance reports into a unified digital platform, enabling real-time monitoring and swift response to potential issues of omission. These innovations promise a paradigm shift in how health and safety standards are upheld in the mining industry.

The advantages of real-time monitoring systems are substantial. These systems enhance law enforcement by furnishing accurate and current information that underpins decisions and ensures compliance with legal standards. They boost operational efficiency by detecting potential issues early, reducing downtime, and optimising resource allocation. Furthermore, real-time monitoring systems contribute significantly to the broader safety and environmental protection objectives by ensuring continuous compliance with health, safety and environmental standards.

Adherence to these standards is a regulatory obligation and a critical factor in mining operations' overall success and sustainability. Non-compliance can lead to severe consequences, including increased accidents, health and safety hazards, environmental damage, legal penalties, financial losses, and reputational harm. Therefore, implementing a real-time permit and compliance system is a significant step in ensuring continuous monitoring and immediate response to any issues, safeguarding all stakeholders' interests.

This paper will unravel these complexities, providing a comprehensive overview of the current state of mining regulations in South Africa and the ongoing efforts to enhance compliance through technological innovation. The paper will give insight into the industry's legislative framework, the real-time systems redefining compliance management, and the strategies that regulatory bodies employ to enforce standards effectively.

The DMRE is the main regulatory body for the mining industry. It is crucial in ensuring compliance with the MHSA and the Mineral Petroleum Resources and Development Act (Act 28 of 2002) (MPRDA), which are the cornerstones of South Africa's mining legislative framework. The DMRE's responsibilities include specific ones such as issuing permits, conducting inspections, and enforcing health and safety regulations.

Due to its history of high-risk activities, the mining industry in South Africa prioritises health and safety. DMRE uses several monitoring systems to ensure that health and safety laws are followed. One important tool is the South African Mines Reportable Accidents Statistics System (SAMRASS), which gathers information on incidents of hazards and accidents. This system's assistance in identifying trends and problem areas makes more focused interventions and advancements possible.

OBJECTIVES

Buried with strict restrictions to protect the environment, safeguard worker safety, and comply with legal obligations, mining operations often find themselves entangled in the laborious and time-consuming process of handling compliance reports and regulatory documentation. This is particularly true regarding ensuring adherence to MHSA rules. The manual handling and processing of regulatory papers severely hamper effective operations and regulatory compliance and add unnecessary stress to the complex mining industry. With numerous parties involved in mining activities, including local communities and government regulators, the need for human resources with expertise to track, analyse, and ensure compliance with MHSA regulations only adds to the burden.

Furthermore, the proposed system would alleviate the burden of manual paperwork, providing ease and comfort in the regulatory process. The complexity and volume of regulatory paperwork permit and compliance reports in the mining industry exacerbate the challenges of maintaining accurate and up-to-date documentation. The constant changes in regulatory requirements and the need for real-time monitoring further compound the difficulties mining companies face in maintaining regulatory compliance. Without a streamlined and automated system, mining operations are at risk of non-compliance, regulatory penalties, and reputational damage. Given the urgency of the situation, there is a compelling need for immediate action. This action should involve the development and implementation of a digital document management system tailored to the specific requirements of the mining industry. With its ability to automatically analyse regulatory paperwork, permits, and compliance reports, this system would enable mining companies to streamline their document management processes, ensure timely regulatory compliance, and mitigate the risks associated with non-compliance with MHSA regulations. Such a system's numerous benefits include improved operational efficiency and reduced penalties and reputational damage risk. Immediate action is required to address these pressing issues. This study highlights the necessity and significance of implementing an automated system that can promote real-time document management practices in the mining industry. This implementation has the potential to significantly improve regulatory compliance, enhance operational efficiency, and contribute to the overall sustainability of the mining sector in the long run. By reducing the environmental impact and ensuring worker safety, the proposed system could lead to a more sustainable future for the mining industry. This study aims to investigate and formulate a thorough understanding of the digitisation of permits and compliance papers in South Africa's mining sector.

METHODOLOGY

Research Design

A mixed-methods strategy is used in this study, integrating quantitative and qualitative research techniques. Surveys and data analysis are used in the quantitative part to evaluate the performance of the present document management systems and pinpoint areas needing development. The qualitative component is used in focus groups interviewed from industry participants to acquire information on the difficulties and attitudes surrounding the digital transition.

Information is gathered from multiple sources, such as:

- Surveys aimed at regulating organisations and mining corporations to assess how well document management procedures work.
- Speaking with stakeholders and industry professionals to learn about the obstacles to digital transformation and to acquire ideas for possible solutions.

Literature review

The DMRE relies on digital tools, like South African Mineral Resources Administration System (SAMRAD), to manage the application process efficiently. The SAMRAD is an online gateway for applying, managing, and tracking mining rights and licenses. Applicants can submit applications electronically, decreasing the need for paper submissions and increasing efficiency. The system promotes transparency by allowing stakeholders to follow application status and guarantee timely compliance with procedural standards. The Department has developed guidelines that conform with the Act and Regulations. Created standardised document submission templates and evaluation tools that align with guidelines and standards. The compliance monitoring system will measure compliance with commitments made in supporting documentation, e.g. PWP's MWP's, NEMA, BEE's, S&LP's and many more. (Dmre.gov.za, 2023)

The system focuses on ensuring transparent processing of applications on the following grounds: Accountability for licensing, Transparency, Promotion of South African mining industry and management of rights

Reporting

Currently, the Department of Minerals Resources and Energy (DMRE) uses two analogue methods to report occupational sickness, accidents, and harmful occurrences. The South African Mines Reportable Accidents Statistical System, or SAMRASS database, is the first reporting system. It was created in 1988 following a review of the entire accident reporting and record-keeping system by the DMRE.

Employers are required to notify the Regional Principal Inspector of Mines of accidents and hazardous events at a mine in accordance with Chapter 23 of the Mine Health and Safety Act 1996 (Act 29 of 1996), as amended. Using the SAMRASS codebook, the data is entered into the South African Mines Reportable Accidents Statistical System, or SAMRASS database. From there, it is evaluated to identify safety patterns. To identify and categorise the main contributing factors to occupational disease management in the South African Mining Industry (SAMI), the second system, the Health Incident Report Occupational Disease System, creates a central database to record the occurrence of occupational diseases for research purposes. Standardising data on safety and disease incidents for administrative ease and statistical purposes is the goal of the Health Incident Report (HIR) Occupational Disease System, which uses the same list of mines granted mining rights under the Mineral and Petroleum Resources Development Act 49 of 2008 as SAMRASS.

When creating and updating these statistical systems, the State, represented by the DMRE, Employers, represented by the Chamber of Mines (Minerals Council), and Organised Labour, represented by the recognised trade unions of the Mine Health and Safety Council (UASA, Solidarity, National Union of Mineworkers, and Association of Mineworkers and Construction Union), provided input. Both the SAMRASS and HIR occupational disease systems adhere to international standards.

The following factors were considered:

Designing the reporting system without increasing the mines was a key factor in the revision process. SAMRASS reporting now includes codes that are in line with industry reporting to Rand Mutual Assurance.

A review of statistical measures, categories and groups for which statistics are provided, and the selection and characterisation of variables to be reported was conducted. Additionally, the new approach has been intended to ease comparison with other statistics and to comply with international standards. To preserve history, coding structures should be consistent with earlier code sets and easily comprehensible to those filling out the required forms.

Data will be distributed and included in the Mine Health and Safety Inspectorate's (MHSI) Annual Report. We'll use explanatory notes, illustrations, and graphs. Data will be provided to show the situation and patterns in the various mining industries.

Only the reporting of accidents, hazardous events, and occupational illnesses is done through the two current systems. They take effect following an incident or accident. To fulfil its mandate to protect mine workers, the DMRE does not have an automated system that they can use to monitor occupational health and safety compliance daily. In addition to monitoring compliance, they are unable to respond quickly to violations or issues that many mining houses may face. ((Editing) Technical Services Department of Mineral Resources, Private Bag X59 ii PRETORIA 0001, South African Mines Reportable Accidents Statistics System Codebook for Mines Directorate (2007)).

Accidents

"The employer must report to the Principal Inspector of Mines in the manner prescribed in this section any accident at the mine that results in (a) any worker dying. (b) If a worker is injured, the injury might lead to death. (c) If a worker becomes unconscious, suffers from severe heatstroke or exhaustion, lacks oxygen, (d) breathes in toxic fumes or gas, or experiences an electric shock or burn, and this incident isn't covered by the next point. (e) If a worker is injured and can't do their usual job or a similar one for 14 days or more, loses a joint or part of it or has a permanent disability because of the injury. If a worker is injured in a way that's not described in the previous point and can't do their usual job or a similar one on the day after the injury".

"The earliest possible method of reporting and confirmation of an accident mentioned in the first paragraphs of regulation 23.1 must be used. Fill on the SAMRASS 1 and 2 forms as outlined in Chapter 21. When an accident meets the requirements for reporting under regulation 23.1, it must be recorded on Forms SAMRASS 1 and 2 (Chapter 21) within three days of the incident becoming reportable. All individuals who have not resumed employment at the time of submitting SAMRASS 2 every month are required to submit Form SAMRASS 9. Any accident mentioned in rule 23.1 paragraph must be recorded on Form SAMRASS 4, which is outlined in Chapter 21, as soon as possible each month".

"If an employee's death which is covered by regulation 23.1(a)—is caused by a rock burst or fall of ground, the employer is required to send the Principal Inspector of Mines the properly filled Form SAMRASS 3 for such a rock burst or fall of ground within 14 days of the employee's death. If an employee dies from an injury after submitting a report following regulations 23.1(b), (c), (d), or (e), or if an employee dies from a minor injury that was not reported, or if an injury causes general sepsis or tetanus, the employer is required to notify the Principal Inspector of Mines right away and submit an

amended report as soon as possible. Where a person's injury referred to in Regulation 23(1) or a dangerous occurrence referred to in Regulation 23.4(o) is related to the use of explosives, in addition to Form SAMRASS 1, the employer must submit the duly completed Form SAMRASS 5, prescribed in Chapter 21, to the Principal Inspector of Mines within 14 days”.

When a person is injured as described in Regulation 23(1) or a dangerous occurrence is described in Regulation 23.4(f) because of a fire, the employer must submit Form SAMRASS 6, as prescribed in Chapter 21, to the Principal Inspector of Mines within 14 days of the occurrence. Where the injury of a person referred to in Regulation 23(1) or a dangerous occurrence referred to in Regulation 23.4(b) is related to subsidence in a coal mine, in addition to Form SAMRASS 1, the duly completed Form SAMRASS 7, prescribed in Chapter 21, must be forwarded by the employer to the Principal Inspector of Mines within 14 days of such occurrence”.

COMPILATION

Industry

The employer of every mine that is being worked must compile an annual report on health and safety at the mine including the statistics on health and safety that must be kept in terms of this Act and the annual medical report. If the employer is a body corporate and employs more than 50 employees, publish and distribute the report, in an appropriate form, to the body corporate's shareholders or members.

Every employer must after investigating, provide a report that analyses the underlying reasons of any accidents, significant illnesses, or health-threatening incidents. Identifies harmful conditions, activities, or procedures that contributed to the accident, serious illness, or health-threatening occurrence, and provides recommendations to prevent similar incidents. A copy of the report must be delivered to the Principal Inspector of Mines and the health and safety committee within 30 days of the accident, serious sickness, or health-threatening incident under investigation. If there is no health and safety committee, the employer is required to deliver a copy of the report to the health and safety representative responsible for the workplace. Within 30 days of receiving the annual report of the Chief Inspector of Mines, the Minister must table it in Parliament. If Parliament is not in session at the end of the period, the Minister must table the report within 14 days of the beginning of the next session of Parliament.

DMRE

After completing an investigation, an inspector must prepare a written report of the findings, recommendations, and any remedial steps. The inspector- must submit a copy of the report to the Chief Inspector of Mines. must supply a copy of the report to the employer and to the health and safety representative, health and safety committee, registered trade union or employee that requested the investigation; and may instruct the employer of the mine concerned to prominently and conspicuously display a copy of the report or portion of it for employees to read.

RESULT

Questions

A key focus was on understanding why these systems remain paper-based and identifying barriers to real-time compliance. The findings from the questions were analysed thematically to uncover relevant themes.

Reliance on Conventional Methods

DMRE personnel and mining companies primarily rely on paper-based methods. They also highlighted that the current system is manual and time-intensive, requiring detailed examination of reports from the mines.

While some mining companies use digital tools like spreadsheets, these lack centralised and integrated real-time tracking functionalities. Manual compliance documentation is often perceived as cumbersome and ineffective, with existing methods falling short of industry standards, based on participant feedback.

Accuracy

Although automation presents a potential solution to compliance challenges, several obstacles to its implementation were identified. Respondents noted that the current technological infrastructure cannot support automated systems for real-time compliance tracking. Upgrading this infrastructure remains essential, and integrating new digital systems with existing ones poses considerable difficulties. Additionally, concerns were raised about the technical skills of current employees, questioning their ability to adapt to new automated processes without extensive training. This indicates the need for personnel upskilling and capacity-building initiatives to facilitate a smooth transition to automated compliance solutions.

Challenges

Despite a strong desire for automation, numerous concerns regarding its implementation were voiced. Respondents worried about the high initial costs associated with transitioning to automated systems, suggesting that financial constraints could be a significant hurdle for some mining companies. A lack of technical infrastructure and expertise was cited as major barriers to the adoption of real-time compliance systems.

Data security and confidentiality were also mentioned as critical issues, with respondents stressing the necessity for robust data protection measures within any automated system. Additionally, the ongoing lack of technical proficiency raised concerns that existing staff might struggle to operate new systems without considerable training.

Flexibility

Despite these challenges, there is a notable and positive inclination towards the adoption of automated compliance solutions. A significant portion of participants expressed a strong willingness to integrate automated systems into their compliance processes, recognizing the potential of such technology to enhance and expedite compliance efforts. The anticipated benefits of automation were frequently mentioned, with participants highlighting improvements in accuracy, efficiency, and overall compliance with regulatory standards.

predicting enhancements in accuracy, time efficiency, and improved compliance with regulatory standards. For example, real-time compliance monitoring was emphasized as a vital advantage, providing instant access to information that could facilitate quicker responses to safety concerns. This level of immediate oversight possesses the capacity to transform compliance processes, mitigating delays and decreasing the frequency of compliance errors generally associated with manual systems.

AI impact

Respondents expressed optimism about the role of machine learning (ML) and artificial intelligence (AI) in future compliance efforts within the mining sector. These technologies are viewed as potentially transformative, with applications in areas such as data analysis, predictive risk assessment, and compliance monitoring. The capacity for real-time AI analysis of extensive datasets could significantly change compliance management by providing insights that are currently unattainable through manual processes. There is a consensus that AI and ML will greatly influence the evolution of compliance management moving forward

Interviews

The study involved interviewing key individuals from various roles within the mining sector. Participants included miners, mine managers, safety officials, shift supervisors, and a representative from the Department of Mineral Resources and Energy.

Efficiency

The proposed digital solution aims to significantly enhance accuracy and efficiency within the mining industry by removing the tedious manual documentation currently required for regulatory compliance. By digitizing data processing and document management, this system could accelerate the tracking, administration, and storage of documents, helping companies avoid delays caused by missing or incomplete paperwork. Additionally, automating data processing would enable quicker responses to critical findings, such as timely dust sample analyses, facilitating immediate corrective actions. The interviews highlighted that the precision of regulatory compliance relies on the accuracy of real-time data, which is essential for swift responses to safety and compliance issues.

Compliance

One significant benefit of the system is its compliance with legal standards, including Sections 54 and 55 of the Mine Health and Safety Act. Mining companies might more effectively maintain current paperwork with the Department of Mineral Resources and Energy (DMRE) by automating and digitising compliance reports, including Level 5 and yearly report. The solution might lessen the possibility of non-compliance, which now leads to regulatory setbacks and further remedial actions for businesses, by providing fast data verification and tracking. The automated system would reduce procedural bottlenecks by enabling quicker reaction times and instant submission of necessary information, such as accident and inquiry records.

The system's ability to handle data in real time would be a crucial component. For example, the system may promptly incorporate the findings of dust collection into predictive calculations, enabling it to warn operators in advance of any dangers. Because it allows for quicker decision-making and more control over environmental health issues, this real-time capacity is extremely significant. As the interviewers said, automated data collecting also decreases human error, boosting precision and trust in data-driven decision-making, which enhances response times to safety and compliance requirements.

Implementation

Since errors might impact the entire compliance process, it is crucial to make sure that the data gathered for input is of the highest caliber. Infrastructure Restrictions: In mining contexts, intermittent internet or wireless connectivity (such as Wi-Fi) can cause system disruptions that impact data access and transmission. To preserve confidentiality and adhere to privacy laws, sensitive data especially that pertaining to medical surveillance report needs to be securely stored. Furthermore, increased reporting frequency can put pressure on companies to swiftly satisfy stricter DMRE requirements.

Consistency

To ensure effectiveness, a standard system across commodities is essential. For instance, coal mines could share a standardized system that meets specific sector requirements, while all platinum operations would have a tailored system. This alignment would help accommodate diverse regulatory changes and adapt to shifting industry demands more smoothly. A universal platform adaptable to varying mining regulations would support companies in adjusting rapidly to any changes in regulations, ultimately creating an industry-wide consistency in compliance practices.

Cost

Establishing a digital compliance system necessitates significant financial investment. Implementing this system would incur costs for software development, hardware installations, and potentially substantial infrastructure improvements, such as Wi-Fi installation in underground mining, which can be expensive. The benefits of automating regulatory procedures and enhancing compliance accuracy underscore the importance of this investment, but finance remains a substantial challenge, particularly for mines with tight profit margins.

Interested groups

Broad stakeholder participation is critical for successful implementation. Collaboration with universities, the Mine Health and Safety Council (MHSC), and other organizations would guarantee that the system is complete, fulfils industrial standards, and receives continued research funding. This collaborative approach promotes shared accountability and allows the sector to access extra resources and technical knowledge during the development and testing phases.

Cons

System failures brought on by network interruptions are a possible setback of automation that could disrupt operations. Furthermore, inaccurate raw data supplied into the system might result in faulty analysis and possible compliance problems. Therefore, to preserve the integrity of the system and prevent expensive mistakes that might compromise safety and regulatory compliance, it is essential to guarantee reliable network access and correct data.

DISCUSSION AND ANALYSIS

One of the biggest obstacles and areas of study gap identification is the absence of a real-time compliance system that allows inspectors to monitor and verify conformity. Mining companies must submit reports, schedule audits, and conduct compliance checks periodically within the current structure. While these methods lay the groundwork for regulatory oversight, they are reactive and prone to errors and omissions. Inspectors frequently rely on digital submissions that are occasionally made or paper-based data that may not be sufficient or current when evaluated. This information flow delay may make it more difficult to intervene quickly when there is non-compliance, which could risk people's safety, damage the environment, or cause financial losses. The DMRE's monitoring capabilities might be revolutionised by incorporating a real-time compliance system. This setup would make use of digital technologies. The DMRE does not yet have a system to analyse mining companies' compliance in real-time. Lack of technology infrastructure and resources is one of the main obstacles to DMRE and mining firms building such a system. The respondents' thematic analysis reveals a strong desire for digital transformation and a thorough understanding of the shortcomings of the current paper-based methods. According to DMRE staff and mining industry representatives, implementing real-time compliance systems promises to improve mining operations' safety, efficiency, and transparency. However, for implementation to be successful, it will be imperative to address technical, financial, and training issues that support such systems.

CONCLUSION AND RECOMMENDATION

The study shows that representatives from mining companies and DMRE staff agree on the shortcomings and inefficiencies of the current procedures. Manual processes hampered effective compliance monitoring and responding to safety hazards and attempts to guarantee thorough oversight were made more difficult by the absence of real-time data access and integration. Despite these difficulties, it is evident that there is potential in using digital, real-time compliance solutions to improve safety, transparency, and efficiency in the South African mining sector.

To track compliance in real time, DMRE and mining companies must give top priority to the creation and deployment of centralised digital systems. This change will facilitate proactive management of health and safety procedures, increase data accuracy, and expedite reporting procedures. Making efficient use of available funds is essential. To guarantee that funds are distributed effectively towards the digital transformation of compliance systems, DMRE and mining companies should work closely together. Combined investment and sharing. Training is required to ensure that employees understand both the technical features of the system and how to use it efficiently to maintain compliance and increase efficiency.

This training process comprises initial onboarding, continuous seminars, and perhaps certification programs for advanced functions, such as data analysis and system troubleshooting. Furthermore, to assist the transition, organizations may need to spend cash for trial testing, allowing personnel to slowly adjust before full deployment.

Establishing open communication routes between DMRE and mining firms is crucial. Regular discussions and feedback provide agreement on system needs, expectations, and milestones during the implementation phase.

Continuously monitoring and evaluating the functioning of digital systems is crucial after deployment. Regular audits and feedback loops may uncover development opportunities, verify compliance with regulatory requirements, and foster a culture of continuous improvement in the industry. Pilot testing is essential to find any problems and improve functionality since staff members will require time and training to become used to the new system

Despite advancements in automation, basic practices should remain in place, including the manual compilation and double-checking of reports. This practice serves as a backup in case of system failure and reinforces regulatory compliance. The transition should be gradual, with continuous reviews to ensure accuracy, compliance, and staff adaptation to the automated system.

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Benjamin Kamala Mwamba

University of Johannesburg

Benjamin is a student at the University of Johannesburg, currently completing undergraduate degree in Mining Engineering. He holds multiple leadership roles, including Class Representative for the 2023 and 2024 Mining and Survey classes, Academic Officer for the 2024 Mining Forum, Mining Engineering Tutor, and Head Residence Academic Advisor. He also represented his university as a delegate for the winning UJ team at the YPC Student Debate. Focused on continuous growth, Benjamin aims to combine his technical expertise with leadership skills to contribute to the future of the mining industry

Striving towards zero harm and fatalities from occupational health conditions

T. Balfour

Minerals Council, South Africa

The mining industry is committed to zero harm and zero fatalities. The Minerals Council's Khumbul'ekhaya strategy is centred on these principles. The full effects of harm due to health exposures are not immediately apparent, unlike safety fatalities. This paper is on ill-health and death due to occupational diseases. Data from the Department of Mineral and Petroleum Resources as well as the National Institute for Occupational Diseases was utilised to show the extent and causes of morbidity and mortality among current and ex-mineworkers. Interventions by the Minerals Council to reduce this mortality and morbidity are explored.

Keywords: Khumbulekhaya, Masoyise, MOSH Learning Hub, respirable crystalline silica, TB

BACKGROUND

Khumbul'ekhaya is a Minerals Council strategy on health and safety that has been developed by the Minerals Council's CEO Zero Harm Forum to drive and sustain the mining industry's pursuit of zero harm. The Khumbul'ekhaya health and safety strategy was launched in January 2019.

The objectives of Khumbulekhaya are to:

- Promote a holistic approach to the elimination of fatalities
- Develop a system of understanding occupational deaths in and beyond employment
- Adopt methods for more effective and competitive training, for example through centralisation and modernisation
- Adopt globally leading practices to learn better and faster from others

The outcomes of safety incidents are immediately visible in the form of injuries and death. Harm from health incidents is however very silent, insidious and can take years, as evidenced by noise-induced hearing loss and occupational lung disease such as silicosis, that take years to manifest.

The industry continues to have significant levels of ill-health and death due to occupational diseases, in current and ex-mineworkers. This paper explores the quantum of these diseases, using data from both the Department of Mineral and Petroleum Resources (DMPR) and the National Institute for Occupational Health (NIOH).

Ill-health and death due to occupational diseases

Through the DMR 165, the DMPR requires companies to submit annual reports on the state of health of employees. Data is collected on employee wellness including the number of employees that died from occupational diseases and those whose services were terminated due to ill-health from occupational and non-occupational causes.

From 2016 to 2023, a total of 187 employees died from occupational diseases in the industry, with 66% being from the gold sector. The fatality rate was 3.4/1000 employees in the industry, and 8.0/1 000 employees in gold for 2019 to 2023. The risk of dying from an occupational disease was 2.4 x higher in the gold sector. The causes of death were almost exclusively due to tuberculosis (TB).

Between 2015 and 2023 there were 6676 employees who were medically incapacitated due to occupational diseases in the industry. Of these, 5508 (82.5%) were from the gold sector. Rates of medical incapacity between 2019 and 2023 were 108/1 000 in the industry and 467/1 000 in the gold sector, a 4.3 x risk.

The NIOH has a PATHAUT database of all autopsies done on current and ex-mineworkers since 1975. In 2021, 13.7% of all bodies at autopsy had active TB, translating to a TB rate of 13 700/100 000 population. This is an extremely high TB rate as the South African national TB rate in 2021 was 513/100 000.

From the DMPR data on mortality from occupational diseases it is clear that TB is the commonest cause of death. TB is also present in a significant number of current and ex-mineworkers whose bodies go for autopsy at NIOH.

Interventions to reduce mortality and morbidity

The key drivers of TB in the gold sector are HIV infection and silica dust exposure.

TB is a preventable disease as its risk factors, prevention, diagnosis and treatment are known and available.

In response to very high TB rates in the industry and the MHSC milestones set in 2014, in 2016 the Minerals Council South Africa launched Masoyise iTB. The focus of Masoyise iTB was to offer all employees in the mining sector HIV Testing Services and TB screening annually. From 2019, Masoyise iTB was renamed Masoyise Health Programme (MHP) and shifted its focus to more comprehensive wellness. MHP works as a multi-stakeholder initiative and promotes international and local best practices on managing TB, HIV, non-communicable diseases and mental health. Optimal HIV management is one of the cornerstones of TB prevention and screening for HIV.

An integral part of MHP was the establishment of an occupational health and milestone electronic reporting system in 2015. In 2023, 93.3% of employees from reporting companies had been offered HIV counselling and 93% were screened for TB. The TB rates in the industry have reduced to below the milestone set in 2014 that the TB rate should be at or below the South African TB rate. The gold sector has however still not achieved this milestone.

Due to the high rates of TB in the gold sector, in 2023 the Minerals Council set up a TB in Gold Mines Working Group to reduce the TB rates in the sector. The key interventions for the group are to reduce silica dust exposure, identify employees with HIV and put them on treatment and to utilise TB reviews for improving management of TB.

The Minerals Council promoted reductions in dust exposures through the Mining Occupational Health and Safety Learning Hub and made great progress in meeting the MHSC milestone on respirable crystalline silica (RCS). In 2023, 5.2% of RCS dust samples were ≥ 0.05 mg/m³, compared to 16.3% in 2015. This is almost meeting the target of 5% and shows major reductions in RCS levels in the industry.

It is envisaged that with these interventions there will be a reduction in TB rates in the gold sector, and this will lead to less incapacity due to ill-health and less deaths.



Thuthula Balfour

Head Health
Minerals Council South Africa

Dr Balfour is a qualified medical doctor and public health medicine specialist with an MBA and Diploma in Occupational Health. She has a wealth of management experience that spans 36 years, 23 of which have been at a strategic level and 16 in the mining industry.

In the mining industry she has led several initiatives in the industry with massive improvements in monitoring performance and outcomes in occupational health.

Dr Balfour currently serve on the board of Department of Labour's Compensation Board and Department of Mineral Resource's Mine Health and Safety Council and also serves on the BUSA Task Team on the National Health Insurance. She served on the South African Health Ministerial Advisory Committee on COVID-19 from 2020 till 2023.

In 2018 she was named as one of the Top 100 Global Inspirational Women in Mining.

Eco-friendly mining: Challenges for the mining supply industry?

O. Drusche

Technische Hochschule Georg Agricola, Germany

Companies in the supply sector of the mining industry can positively impact environmental, social, and governance factors. These factors significantly affect corporate performance, investment returns, and risk reduction. However, it is predicted that the demand for mineral resources will increase in the coming years, leading to higher energy consumption, emissions, and waste production in mining and processing. The mining industry accounts for up to 10% of global energy consumption, with the process of crushing rocks alone responsible for approximately 3% of this usage. To achieve the goal of net zero emissions, mining companies must commit to credible, science-based plans that include targets for reducing greenhouse gas emissions. Suppliers are taking measures by adapting their product portfolios to reduce emissions in the mining industry. The objective is to expedite progress in tailings and waste management, water stewardship, and most importantly, achieve net-zero emissions through the implementation of new technologies. This paper explores options beyond conventional product development and efficiency improvements, presenting the sustainable business model innovation as a potential solution.

Keywords: mine-to-market value chain, circular economy, sustainable business model innovation, ESG factors, risk management.

INTRODUCTION

While efficiency-boosting product developments are a positive step, they alone are insufficient for achieving genuine environmental relief. To address these issues, new innovations are required that were not previously available or considered feasible. Identifying technology deployment pathways and associated resources is crucial to support positive social and environmental outcomes. It is also important to build community and supply chain resilience and ensure a just transition. A collaboration should also be intentional. The question remains whether the supply industry is fully aware of the extent to which the mining industry will need to change or what changes will be triggered. Furthermore, the establishment of a circular economy is gaining importance due to newly established legal requirements for both suppliers and customers.

Mining is known to cause high ecological and social impacts especially due to its extractive nature on one hand, and its resources and reserves mostly being in developing or emerging economies on the other hand.

With that said however, the mining industry itself also needs to decarbonise and play a role in meeting the overall aims regarding decarbonisation. The industry is a significant user of energy overall. Across the entire industry, it is estimated that 12 EJ of final energy is consumed or 3.5% of total final energy globally (Engenco, 2021). The mining industry is known for its high greenhouse gas (GHG) emissions due to the use of heavy machinery and the energy-intensive nature of mining operations. The GHG emissions associated with primary mineral and metal production was equivalent to approximately 10% of the total global energy-related GHG emissions in 2018.

However, the mining industry is of pivotal importance in the transition towards sustainable energy, supplying critical minerals, including copper, lithium, nickel, cobalt and rare-earth elements, which are necessary for electric vehicles and renewable energy. Considering the transition towards net-zero emissions, it is anticipated that demand for these minerals will experience a significant increase.

Figure 1 shows that an energy system powered by clean energy technologies differs profoundly from one fuelled by traditional hydrocarbon resources.

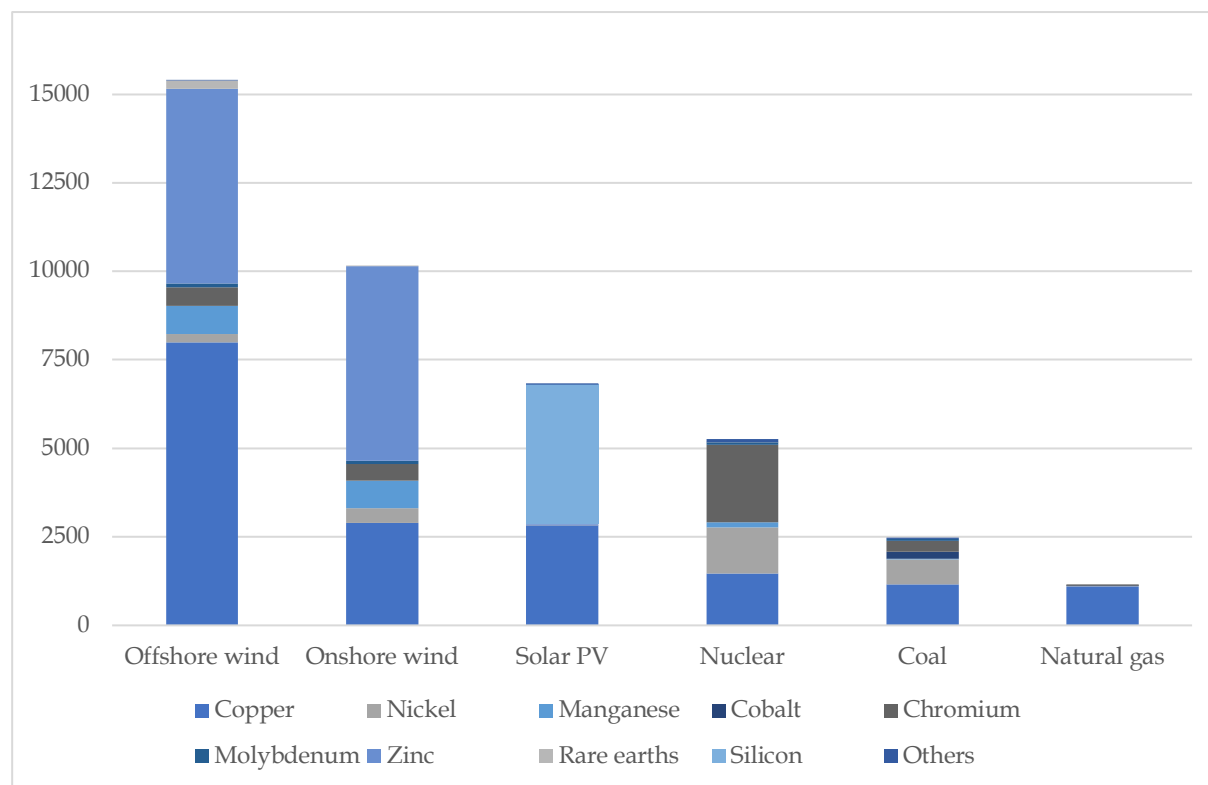


Figure 1. Minerals used in clean power energy technologies compared to other power generation sources [kg/MW] according to (International Energy Agency, 2022).

The mining industry is at a turning point where the course for its future is set. Mining actors are confronted with a growing demand for raw materials, decreasing ore grades, and growing pressure through 'responsible investing' depicted by environmental, social, and governance principles.

The trend of increasing energy demand to produce the same quantity of some metals compounds the problems of increased metal demand due to the pressures of new technologies and increasing population. For green technologies to be implemented effectively, it is necessary that the mining industry and regulators accurately and transparently account for GHG emissions to implement mitigation strategies.

Pathways for climate change impact mitigation in mining

There are many possible options to reduce the greenhouse gas emissions from mining. Broadly, they can be split into four sections, as shown in Figure 2: the reduction of fugitive emissions; increased resource recovery; reduction in energy use and change in energy production; and biological solutions focused on offsetting and sequestering the CO₂e that is released during mineral extraction and processing.

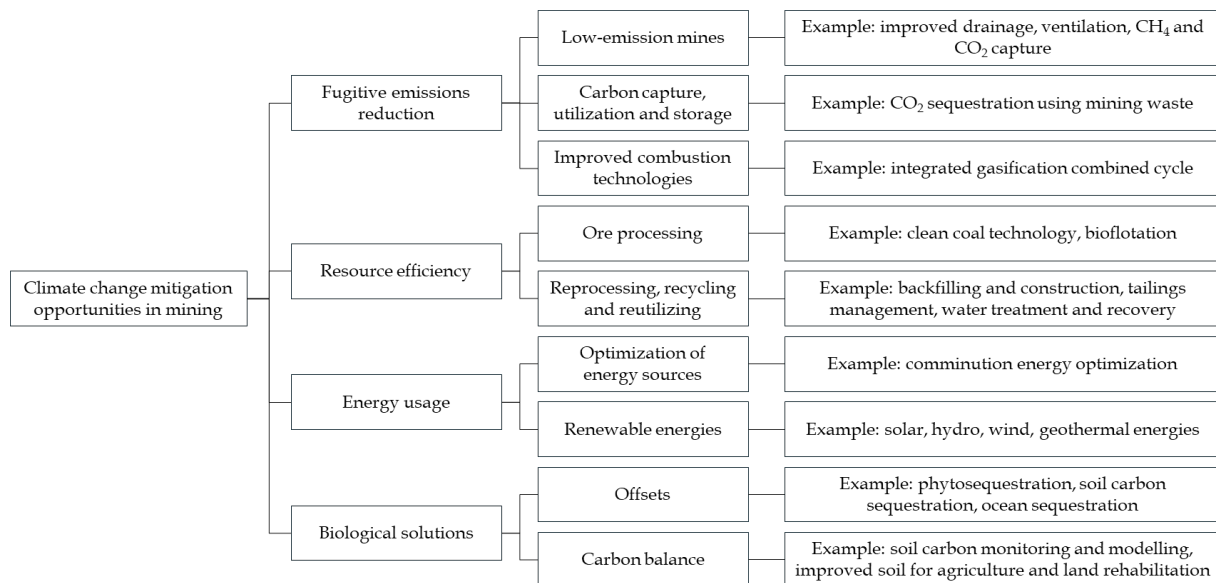


Figure 2. Pathways for climate change impact mitigation in mining according to (Azadi, Northey, Ali, & Edraki, 2020).

The objective of resource efficiency is the conservation of natural resources, with a particular focus on the reduction of raw material usage (including water), the minimisation of land utilisation and the avoidance of land degradation. Additionally, the goal is to minimise environmental pollution and, consequently, to safeguard the livelihoods of both current and future generations.

RESOURCE EFFICIENCY

Detailed life cycle analyses are conducted with the objective of evaluating the environmental impact of machinery utilised in the mining and beneficiation process on climate change. This is accomplished by measuring the life cycle GHG gas footprint of the input.

Some companies have endeavoured to identify those business activities that fall within the scope of the European Union (EU) taxonomy, with the objective of developing a reporting framework that aligns with the relevant criteria. The initial stage of evaluating the alignment of an eligible activity with the EU taxonomy is to demonstrate that the activity contributes to significant life cycle GHG gas savings in comparison to the most effective alternative solution.

The findings of the analyses can then be used to identify the most effective methods for developing and implementing technologies to mitigate climate change. Some examples of efficiency improvements within the mining industry: the Sibanye-Stillwater mine, in South Africa, has cut the energy consumption of its ventilation systems by 62% by better controlling fan speed and air circulation. Rio Tinto's Gudai-Darri mine in Western Australia has introduced driverless vehicles, which have been shown to increase output by 15 to 20% while reducing costs and fuel consumption (PwC, 2023).

Energy usage

Renewable and green energies: the falling costs of solar and wind power have made renewable energy one of the most reliable ways for miners to decarbonise while also reducing their energy costs, which tend to be higher than average. Installing renewables near mine sites, which are usually remote, also helps improve their energy security.

For example, Chilean copper miner Codelco is reducing emissions by 15,000 tonnes of CO₂e and saving US\$2 million per year by using solar power. As the costs of batteries and electrolyzers continue to fall, we should see rapid growth in the use of renewables and hydrogen in mining in the near future.

BHP is working towards a 30% reduction in operational GHG emissions by the 2030 financial year, with a 2050 net-zero target. The company plans to replace its diesel-powered haulage fleet with electric alternatives, beginning with the introduction of electric drive trucks and trolley-assisted systems. BHP aims to achieve 100% renewable electricity in grid-connected operations by 2030, focusing heavily on renewable energy projects, including solar and wind power (Skarn Associates, 2024). Anglo American's Mogalakwena mine in South Africa has begun using hydrogen-powered trucks, which can reduce CO₂e emissions by more than 2,000 tonnes per vehicle per year. By replacing its diesel trucks and using hydrogen produced onsite, the mine is on track to significantly reduce its direct (Scope 1) emissions (PwC, 2023).

Influence of ore grade decline on energy consumption and emissions

As the global population continues to grow and the demand for materials increases, the exhaustion of mines is becoming a significant issue. Ore grades are rapidly declining, and the expected deployment of clean technologies for the energy transition will further exacerbate this problem.

A reduction in ore grades is typically accompanied by an increase in energy consumption, although improvements in technology may potentially offset some of these higher costs to a degree. Given that most of the energy consumed in mining and refining operations is derived from fossil fuels, it is probable that emissions from the mining industry will increase in line with rising demand and declining ore grades. The clean energy transition, which aims to significantly reduce GHG emissions, may encounter a rebound effect if this issue is not given sufficient consideration (Calvo, Palacios, & Valero, 2022).

The example of copper, which is crucial for clean energy production, can be used to illustrate the impact and origin of the rebound effect. Most GHG emissions from copper come from mining and processing emissions and, therefore, a decline in ore grade could increase the emissions intensity per unit output of copper. For example, the emissions intensity for an open-pit operation with a 0.8% head grade would increase by approx. 28% if the grade were reduced to 0.6%. Emissions intensity is greatly influenced by mine type and processing route (International Finance Corporation, 2023).

CURRENT ENERGY USE BY EQUIPMENT ACROSS THE MINING INDUSTRY

Electricity consumption for comminution energy is one of the prime costs of production, as well as a major contributor to the carbon footprint of the mining industry, partly due to declining ore grades. The data regarding the proportion of energy consumption within the value chain for the extraction of mineral raw materials exhibit considerable variability. This can be attributed to the differing observation bandwidths and the nature of the processed materials.

The life-cycle assessment work by Norgate and Haque (2010) provides insight into the split of energy consumption for a typical underground operation with a concentrator. This study indicates that just over 50% of total site energy is in the mining operations (~55%), with the remainder of energy consumption occurring in the processing plant (Norgate & Haque, 2010). Energy use in the mining operations is 40% electricity (primarily ventilation) and 60% diesel (for loading and hauling). In the processing plant, most energy consumption occurs in grinding (90%) with the remaining energy consumption in this study being attributed to flotation (Engeco, 2021).

Ballantyne *et al.*, (2014) completed an audit of the energy consumed by comminution in Australian copper and gold producing mines. On average, 36 % of the energy utilised by the mines was found to be consumed solely by comminution processes. In summary, open pit operations utilise mainly diesel as the energy source for extraction and transport of material to the processing plant. The percentage splits of total site energy consumption are similar with close to 60% of total site energy being consumed in mining operations and the remaining 40% being consumed in the processing plant.

Figure 3 shows the energy use by equipment category in the U.S. mining industry by category. The mining section with the operations drilling, blasting, digging and materials handling accounts for 46% of the total, while the processing section contributes 54%. The largest energy consuming equipment

types are grinding (40%) and materials handling diesel equipment (17%) (U.S. Department of Energy, 2007).

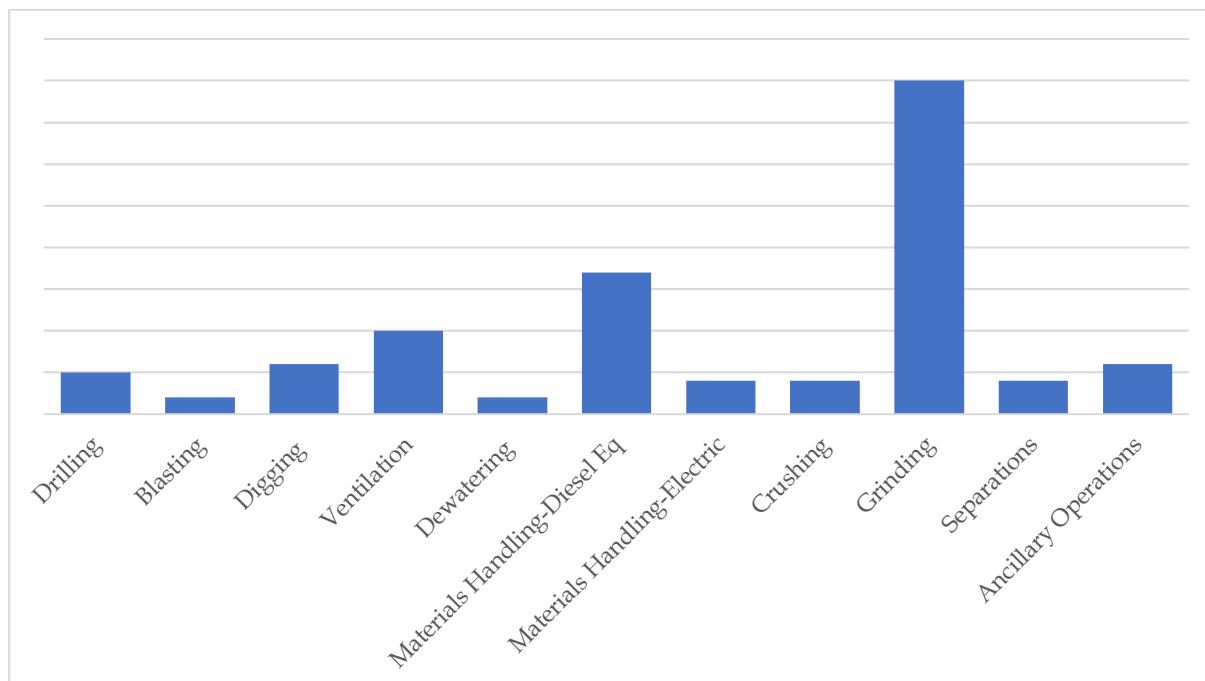


Figure 3. Contribution of current energy use by equipment across the mining industry according to (U.S. Department of Energy, 2007).

The top two energy-consuming processes, materials handling (diesel equipment) and grinding, offer opportunities for energy savings. It is suggested to improve comminution circuit design to mitigate energy usage.

Materials handling

In future, resources will inevitably be mined deeper and at lower grades than today. At mines with traditional truck haulage operations this will require the number of trucks to increase significantly, due to longer haul distances - and consequently longer cycle times - associated with deeper pits. However, an increase in truck numbers naturally raises labour and fuel consumption: factors that contribute to higher operating costs. Trucks are also the largest single source of emissions at a mine (Mohammadi, Hashemi, & Moosakazemi, 2011).

As a result, continuous in-pit crushing and conveying (IPCC) systems are gaining attention, as their numerous advantages over traditional truck haulage are recognised. IPCC is a general term for a more continuous mining process. In IPCC systems, the primary crushing unit is located close to the face, where it reduces the size of material so it can be conveyed rather than hauled by trucks. The crucial driver behind this is that haulage cost are the most significant costs in mining. Continuous systems equipped with conveyors are substantially more economical than trucks (Braun, Hennig, & Lottermoser, 2017).

One of the main selling points of IPCC systems is their ability to reduce operational costs and emissions, which is in line with current industry targets. IPCC is essentially free of direct hydrocarbon emissions; it is also less labour intensive and more energy efficient than conventional truck haulage. The ratio of moved material to total moved weight for a mining truck with a 327-tonne payload capacity is almost 1:2.6, which means the percentage of material moved is less than 40% of the total moved weight on one round trip. At a ratio of 1:1.2 of moved material to total moved weight, and without empty return trips, this percentage is more than 80% for an average overland conveyor with a 10,000 tph throughput, 1,000 m length, and belt speed of 5 m/s (Carter, 2023). In addition, the conveyor belt is driven by electric motors that are around 95% energy efficient (Soofastaei, Karimpour, Knights, & Kizil, 2018).

IPCC systems also reduce the number of haul trucks in the mine and therefore the traffic. The need for fewer operators reduces the number of people exposed to hazards, as well as reducing the potential for human errors. In addition, reducing the number of haul trucks leads to lower generation of dust and cuts the need for regular maintenance, such as tyres, filters, and lubricants. An advantage for electric mines in general is the reduction of local NO_x emissions.

The system was able to energy estimate efficiency for open-pit extraction, comparing the use of continuous and discontinuous machinery. For this purpose, the complete extraction process is broken down into 'n' partial processes, each containing crushing and/or transport process (Raaz & Mentges, 2011). The advantages of IPCC were enumerated for a copper mine in Kazakhstan with annual production capacity of about 40 million tons. The copper deposit was intensively examined and planned with regard to the use of IPCC. The open pit mine has now been opened and the use of semi-mobile crushing plants is on the shortlist. With average transport distances of 0.75 km and a pit depth of 670 m, the current truck-and-shovel operation consumes approx. 50 million litres of diesel per year. We determined that, by switching to an IPCC system, the mine would gain significant financial and environmental benefits.

To achieve the required capacity, two redundant crushing plants, each with a capacity of 8000 tph, were planned. Its semi-mobile design will significantly reduce diesel haulage, resulting in a 93% drop in annual diesel consumption to just 3.7 million litres. And although the use of conveyor belts increases electricity consumption, annual CO₂e emissions will still fall by about 99,500 tons compared to diesel-powered haulage: a 73% reduction.

Crushing and Grinding

The strategies against the rising energy consumption can be split into two groups: first to avoid comminution and second to use more efficient comminution technology. The application of Eccentric Rolls Crusher, High Pressure Grinding Roll (HPGR) and the Vertical Roller Mill (VRM) for ore grinding is part of the second strategy. Size reduction processes, which encompass crushing and grinding, represent a significant part of the capital as well as the operating cost in ore processing. Advancing the understanding of and improving such processes is worthwhile, since any measurable enhancement may lead to benefits, which may materialise as reductions in energy consumption or wear or improved performance in downstream processes.

The energy consumption of ore comminution, particularly of the grinding processes, is set to increase in the coming years for well-known reasons. The deterioration in ore grades is forcing mining companies to mine and process a greater quantity of raw material to ensure that the refining industry is adequately supplied with ore concentrates. Furthermore, the ore textures are becoming increasingly complex, and the valuable minerals are becoming finer in grain size compared to ores from the previous decades. This necessitates additional grinding to achieve sufficient liberation of the minerals. It is possible that these trends may result in a fourfold increase in the energy consumption associated with the comminution of principal metal ores by the year 2030, in comparison to the current levels.

HPGR and/or VRM are the most efficient grinding tools available, and the finer you grind, the wider the gap gets between them and tumbling mills (SAG mills and ball mills). The reasons for those advantages are, among others, the inter-particle and dry in-bed grinding principles.

The development of the HPGR technology originated from the fundamental studies that Prof. Dr. Klaus Schönert, the inventor of the HPGR, and his colleagues performed on interparticle breakage (Rashidi & *et al.*, 2017). The HPGR, as an energy-efficient dry comminution machine, was first utilised industrially in 1985 (Chelgani & Neisiani, 2023) in the cement industry for the grinding of limestone, clinker and sometimes slag. They were quickly recognised as a potential means of improving product quality while reducing energy and wear part consumption. As a result, considerable efforts have been made to adapt the technology for use in other industries.

Further development of the wear protection capabilities has enabled HPGRs to be used with great success in a wide range of mining applications. The first applications began in iron ore concentrate

grinding. In the meantime, the optimization of roll surfaces with studs has significantly increased roll life and the technology is now well established for ore and hard rock applications (Heinicke, Lieberwirth, & Pfeifer, 2022).

HPGRs can be utilised in both closed and open circuits by using screens or air classification. It was documented that using an HPGR arranged in the closed-circuit can improve the grinding process. The main advantages of this type of HPGR are enhanced throughput (by up to 25%), reducing the specific energy consumption (Altun, Benzer, Dundar, & Aydogan, 2011), and no grinding media being required. Rosario and Hall (2010) have demonstrated that energy savings in hard ore applications are within the range of 7.7% and 18.4% (Rosario & Hall, 2010). Morell (2022) reports using HPGR-HPGR circuits instead of AG/SAG-ball mill circuit can reduce the energy consumption up to 30% (Morrell, 2022). A study carried out in collaboration with the University of British Columbia to develop and demonstrate the use of HGPR compared to the operation of ball mills resulted in energy savings of over 60% in the grinding plant and 50% in the entire circuit (Gagnon, *et al.*, 2022).

The low efficiency of tumbling mills is well documented in the literature. For example, Wills (2016) references sources which estimate values between 1% and 26%, while Bouchard *et al.*, (2019) estimate that the average energy efficiency is 9% (Wills & Finch, 2016); (Bouchard, LeBlanc, Levesque, Radziszewski, & Georges-Filteau, 2019). It is anticipated that VRM will offer an enhanced level of comminution energy efficiency in comparison to tumbling mills. It is anticipated that VRM can offer improved comminution energy efficiency over tumbling mills.

The VRM has been used extensively for comminuting both cement raw materials and minerals like limestone, clinker, phosphate, manganese, magnesite, feldspar and titanium. This mill type combines crushing, grinding, classification and drying operations in one unit and has advantages over conventional machines and literature reports that 15% energy saving is achievable in cement grinding operations when compared to ball milling circuit.

The improved performance in cement grinding operations encouraged several research studies on ore grinding applications. The study from Altun *et al.*, (2015) concluded that 18% saving in specific energy consumption is achievable together with the less wear on the internal components (Altun, Gerold, Benzer, Altun, & Aydogan, 2015).

Mc Elroy *et al.*, (2024) discusses the application of VRMs in mineral processing, specifically focusing on comminution circuits for various types of ores, including copper, gold, and complex sulphide ores. A semi-industrial VRM pilot mill was used to test three different ore types: copper ore from Aitik, gold ore from Kankberg, and complex sulphide ore from Garpenberg. These tests aimed to assess the grindability and energy efficiency of VRMs compared to traditional autogenous (AG) milling. The result is that VRMs can significantly reduce energy consumption in comminution circuits compared to AG mills. For instance, the VRM energy consumption, was shown to be much lower than that of AG for similar product sizes (Mc Elroy, Woywadt, & Kovacs, 2024).

Today, the VRM is largely conceptual in mining. The issue that arises in the context of mining, as opposed to cement, is that each ore body is inherently distinct. Variations in bulk density, hardness, and competency, among other factors, influence the necessary grinding power and/or the selection of appropriate equipment. The VRM technology has the potential to offer significant benefits in terms of energy efficiency and operational flexibility in mineral processing, but further research and development are necessary to fully understand and optimise its application across different ore types.

Redesign of grinding circuits for new operations

The optimisation of grinding circuits, as previously outlined, is primarily applicable to existing grinding circuits. In the case of a new greenfield site, there are significant opportunities for optimisation when rethinking the design of the grinding circuit to take advantage of new technology. The advent of new technology, such as HPGRs, VRMs and stirred mills/vertical mills, has the potential to supplant traditional semi-AG grinding/ball mill applications, thereby achieving comparable outcomes.

However, this is contingent upon the suitability of the specific ore type and processing requirements to these comminution circuits.

In certain instances, the latest grinding technology can prove to be markedly more energy efficient than traditional comminution circuits. It should be noted that SAG and ball mills require a considerable amount of energy to operate, due to the necessity of turning the mill itself and lifting the grinding media. The latter is particularly relevant in the case of SAG mills, which are relatively large pieces of equipment. In particular, SAG mills are not an efficient means of processing competent rocks. Furthermore, both mills consume grinding media, the embodied energy of which has a significant impact on overall CO₂ emissions.

The business case for replacing grinding circuits with newer technology that is more energy efficient is more compelling when considering a greenfield site or an expansion, as a brownfield site has already incurred the initial capital expenditure on the grinding circuit. Nevertheless, there are instances of brownfield sites where limitations in energy supply and the availability of grinding energy can impede the overall throughput of the entire site. It is recommended that additional throughput in grinding circuits resulting from the unlocking of additional energy capacity due to energy savings be included as a factor in business cases when exploring the potential of equipment and circuit changes.

The products and systems presented here facilitate an increase in efficiency, which leads to an enhancement in productivity. Nevertheless, in the long term, these developments will not result in any significant ecological benefit, particularly given the decline in ore content and the concomitant rise in specific energy consumption.

Comminution activities represent more than 40% of the total final energy consumption in the areas studied. This makes comminution a key area in which energy savings efforts can be focussed in the short to medium term. It is imperative that these novel and sophisticated technologies, like the VRM, be further introduced as part of market development strategies. It is similarly important to recognise that the grinding sector still offers significant scope for further energy reduction.

OPTIMISED CONTRIBUTION OF ENERGY USE

The author has sought to apportion the potential for optimisation of the respective technologies in accordance with the contribution of the current energy consumption of machines in the mining industry. It should be noted that this approach is subject to a certain degree of uncertainty, as relative rather than absolute values were used. Adopting a conservative stance, the total optimisation potential along the shown operations and stages is calculated to be -24%.

The greatest potential for optimisation is observed in the IPCC. The electrification of the transport process has the potential to result in significant reductions in GHG emissions. Regarding the processes of crushing and grinding, there is still scope for improvement on the part of the supply industry. Regarding the area of separation, it seems probable that the reduction potential is greater than that indicated here.

This overview is concerned with the direct energy consumption and emissions generated by mine sites. It should be noted that indirect emissions also contribute to the overall impact of a mine site. These emissions occur because of inputs and outputs within the mining value chain. The reduction of indirect emissions is contingent upon the minimisation of water consumption. This is of particular importance in arid regions, where desalination is a crucial process for producing water for the site. The production of water through desalination is a highly energy-intensive process, with an estimated consumption of up to 5 kWh for every m³ of desalinated water produced (Jia, Klemeš, Varbanov, & Alwi, 2019). The emission of 5.1 kg of CO₂ equivalents per cubic metre of desalinated water is dependent on the power source in question.

Where the ore type allows, there are opportunities for dry grinding (preferable with VRM) and dry classification - which will reduce the amount of water use for the site.

It has been demonstrated that comminution circuits represent the largest single consumers of final energy for hard rock mining operations, accounting for one quarter of the total final energy consumed in mining. It can thus be concluded that incremental enhancements in comminution circuits can result in substantial reductions in both energy consumption and GHG emissions.

BUSINESS MODELS FOR SUSTAINABILITY

It is evident that the conventional methods of achieving sustainable development and technological process and product innovation are inadequate for effecting the radical transformation of companies towards genuine and substantial sustainable development. The resource efficiency of mining companies must grow faster than quantitative sales to ensure economic success by decoupling environmental and social problems.

However, despite the impressive displays of cutting-edge equipment and visions of a more efficient industry, several high-profile disputes serve to illustrate that the future of mining depends on the integration of technology with environmental stewardship and broader community concerns.

One illustrative example is the Kudz Ze Kayah project, operated by BMC Minerals in the Yukon Territory, situated near British Columbia. The development is a copper, zinc, and gold operation that has become the subject of a legal dispute with the neighbouring Kaska nation. The project obtained governmental authorisation earlier in 2024; however, the Kaska nation asserts that the mine is not economically viable and will encroach upon their traditional territory. In an appeal lodged last week, Kaska lawyers alleged that the consultation process was constrained and that their concerns were ignored. As the litigation continues, it remains unclear how operations at Kudz Ze Kayah will be affected. The dispute exemplifies a broader tension in contemporary mining practices, wherein the demand for critical minerals and the interests of residents directly affected by major projects are in conflict (Rajkotwalla, 2024). The increase in profitability, achieved through higher resource productivity, as well as the pursuit and establishment of an efficiency strategy, are assumed to be fundamental to the development of a more sustainable business model. The concept of a business model for sustainability is regarded as a key lever for organisational and operational sustainability within the raw materials sector. Its objective is to reduce the frequency of adverse events and the number of damages, thereby enhancing the sector's overall resilience.

The precision of determining business model decisions and dependencies between business model patterns can be increased by expanding the scope to the next stage of the value chain. This includes in particular the consideration of the circular economy and 'Regenerative life cycle concepts'. Circular economy shall be interpreted following the definition of Kirchherr *et al.*, (2017): "*A circular economy describes an economic system that is based on business models which replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations.*" (Kirchherr, Reike, & Hekkert, 2017).

Quantifying the potential CO₂e reduction from implementing circular economy and business models for sustainability in mining is complex and context-dependent, as it varies based on factors such as the specific mining operations, geographic location, technologies used, and the extent of CE practices applied. Here are some general insights:

- Recycling and reuse of materials: recycling metals like aluminum, copper, and steel can save up to 60-95% of the energy required for primary production. For example, recycling copper saves around 85% of energy compared to primary production.
- Improved resource efficiency: implementing circular practices such as reducing waste, improving resource recovery, and designing for longevity can decrease CO₂e emissions in mining by around 10-30%, depending on the type of materials and processes involved.

- Use of secondary materials: using secondary materials instead of virgin resources in the supply chain could lead to a 20-50% reduction in CO₂e emissions, depending on the material type and source.

Given these considerations, the overall potential CO₂e reduction from implementing circular economy and sustainable business models in mining could range at 30% depending on the depth and scope of the practices adopted.

CONCLUSION

Because of its extracting and processing mineral resources, the mining industry is widely regarded to be one of the most environmentally and socially disruptive business activities in the world (Peck & Sinding, 2003). Indeed, many of the major environmental disasters and human rights incidents that have led to growing public concern of the stakeholders about the sustainable development have taken place in the mining industry. In this discussion, the aspects of maintaining the social licence to operate play an increasingly decisive role, whereby the social licence to operate reflects an informal social contract that aims to bridge the gap among the views of the most important stakeholders involved in mining activities (Komnitsas, 2020). It is insufficient to rely on economic gains alone to ensure the continued functioning of a mining operation. Furthermore, the implementation of technological advancements is contingent upon the establishment of a secure operational framework.

There are several opportunities available to reduce energy consumption and emissions in the mining and mineral process industry. Opportunities involving the replacement of traditional comminution equipment with new, efficient technologies which consume less energy and reduce or mitigate grinding media, preconcentration and others. In addition, if zero emissions energy sources are deployed for mobile and stationary equipment e.g., renewable energy, then the mining industry may be able to achieve zero emissions.

When introducing novel technologies and innovations, the possibility of substitution in the sense of creative destruction (cf. Schumpeter 1997 (1912)) cannot be discounted. It would be wrong to ignore the possibility of product cannibalisation in this case. The phenomenon of product cannibalisation can be defined as a reduction in sales volume or revenue when a company introduces a new product or a new version/style of an existing product, thereby diverting consumer spending from existing products. On the other hand, Hart and Milstein (1999) describe the concept of creative destruction as a prerequisite and central force for the transition to a sustainable society and emphasise this: “Overall, innovators and entrepreneurs will view sustainable development as one of the biggest business opportunities in the history of commerce.” (Hart & Milstein, 1999).

The simultaneous application of generic sustainability strategies would represent the optimal basis for a sustainability-oriented business model. Nevertheless, constraints emerge due to the competencies and distinctive attributes of the potential value creation stages. The implementation or application of the efficiency and consistency strategy is acknowledged as the fundamental prerequisite for ecological remediation. The circular economy and business models for sustainability could be identified as the most promising route to long-term corporate success and at the same time a guarantee for human wellbeing within the planetary boundaries. Business models for sustainability are the lever of organisational and operational sustainability within the raw materials sector to reduce hazard and vulnerability, by means of frequency of events and number of damages.

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Olaf Drusche

Lecturer

Technische Hochschule Georg Agricola Bochum, Germany

Olaf Drusche is a doctoral mining and processing engineer by profession and holds an MBA. Over the past 20 years, Olaf has worked in various companies and positions, all related to mining and mineral processing. In addition to his work at FLSmidth Mining Technologies in Germany, Olaf is a lecturer at the Georg Agricola University of Applied Sciences in Bochum, Germany, in an international master's programme for the modules 'Sustainable Management and Communication' and 'Controlling, Leadership and Corporate Governance'.

Enhancing underground mine safety through rockmass instrumentation

L. Scheepers¹, P. Lenegan¹, F. Pienaar², and H. Hoogenboezem³

¹SibanyeStillwater Gold Division, South Africa

²Mining Product Developments, South Africa

³Hoogenboezem Industries, South Africa

Mining operations inherently involve risks, and ensuring the safety of workers in underground mines is of paramount importance. In recent years, advancements in instrumentation have provided valuable tools for monitoring and managing safety conditions. In this paper, we delve into the role of data-driven approaches and specialised instruments in enhancing mine safety.

1. Instrumentation Development: Closure meters
 - A closure meter has been developed as a robust and reliable instrument designed specifically for underground mine use. Its primary function is to measure closure in a narrow tabular stope accurately.
 - Its versatility allows it to adapt to various situations. Whether readings are taken every second or every 10 seconds depends on the specific context.
 - With readings taken every 10 seconds, it can operate for a year on a single battery charge.
2. Data Flow and Real-Time Monitoring
 - Closure readings are collected by intermediate devices, transferring data to the surface via the mining infrastructure.
 - Surface personnel can then access real-time closure readings. This capability would allow for immediate response to any anomalies or safety concerns once implemented mine-wide.
 - The accuracy of closure measurements achieved by the SmarTrac is approximately 0.01 mm. Additionally, we capture ride data – the perpendicular movement relative to the instrument's axes – with lower accuracy (around 1 to 2 mm).
3. Insights from Large-Scale Data Collection
 - Deploying multiple closure meters in a test area of the mine yields fascinating insights into the rockmass response. This will be expanded to more areas on the mine.
 - Blasting effects become quantifiable. By analysing closure data before and after blasts, we can assess their impact on mine stability.
 - Seismicity is a critical factor in our deep level mines. By correlating closure variations with seismic events, we gain a deeper understanding of safety risks.
 - The challenge lies in aggregating sufficient data to predict unsafe situations reliably. Our ongoing research aims to address this challenge.

In summary, comprehensive data collection using instruments like the SmarTrac empowers mine safety professionals to make informed decisions. By leveraging real-time insights, we move closer to a safer mining environment.

INTRODUCTION

Mining operations inherently involve risks, and ensuring the safety of workers in underground mines is of paramount importance. In recent years, advancements in instrumentation have provided valuable tools for monitoring and managing safety conditions. In this paper, we delve into the role of data-driven approaches and specialised instruments in enhancing mine safety.

Background

“Underground closure had been measured in isolated cases in various mines. Francois Malan (Malan, 2003) had the following to say:

This guide was produced in response to a need identified in the South African gold mining industry for a better understanding of the closure behaviour of tabular excavations. Although references to closure measurements can be found dating back to the early 1930s, research in the SIMRAC fundamental projects GAP332 and GAP601b indicated that continuous closure recordings contain much important data which are lost with the traditional method of closure measurement (which consists of installing closure pegs and taking manual readings on a daily basis or less frequently).

The rate of closure is a very important parameter for support design and therefore impacts indirectly on safety. Continuous closure measurements also appear to be useful to identify different geotechnical areas and the hazards associated with each area. The objective of this guide is therefore to:

- create awareness of the need to do continuous closure measurements on a more regular basis,
- standardise the closure terminology used in the industry,
- illustrate the effect of mining rate on the rate of closure,
- highlight the effect of measurement position on the rate of closure.
- Illustrate the value of the closure ratio parameter to identify different geotechnical areas and hazardous conditions.”

Scope

This paper is limited to the installation of closure meters and accelerometers at SibanyeStillwater Gold Division, the monitoring of data from these on surface, and the relationship between trends in data observed and physical events such as blasting and seismic events.

Instrumentation Development: Closure meters

The SmarTrac was developed for use in underground mines to monitor closure to either warn of excessive ground movement or to log closures for separate data analysis.



Figure 1. A SmarTrac.

The device consists of two PVC capped tubes that are spring loaded for easy installation. Positioned within the tubes is a device that monitors the relative movement of the two ends of the tubes. A flashing light is available to indicate the status of the device.

In the version of SmarTrac used at SibanyeStillwater, there is no on-board logging of data. All data are transmitted live using radio transmitting (LORA). The device can be programmed to customer requirements and can be programmed to measure deformation at various frequencies from 1 second up to one reading per day. Most instruments at SibanyeStillwater collect and send data every 10 seconds, but there are also some instruments with a one second frequency.

In short:

- A closure meter has been developed as a robust and reliable instrument designed specifically for underground mine use. Its primary function is to measure closure accurately.
- Its versatility allows it to adapt to various situations. Whether readings are taken every second or every 10 seconds depends on the specific context.
- With readings taken every 10 seconds, it can operate for a year on a single battery charge.
- The accuracy of closure measurements achieved by the SmarTrac is impressive—approximately 0.01 mm. Additionally, we capture ride data—the perpendicular movement relative to the instrument's axes—with slightly lower accuracy (around 1 to 2 mm).

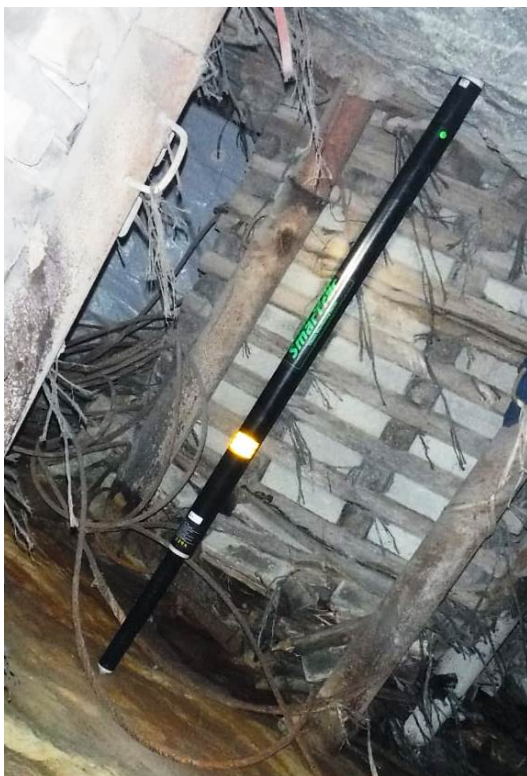


Figure 2. Wide stoping width range is possible.



Figure 3. SmarTrac installed underground.

Instrumentation Development: Accelerometers

An attempt to measure micro fracturing, possibly related to closure preceding large events, is currently being carried out at Masikhane shaft (Driefontein mine). Traditionally gold mines in South Africa use a seismic network array of mine-wide 4.5Hz geophones. These arrays of sensors are suitable for measuring larger events but are not ideal for recording fracturing very close to the stope face.

To achieve the recording of small micro seismic events (fracturing), two inexpensive 8 G mems accelerometers were installed in a designated project area located in the VCR reef horizon. These accelerometers, located at two different working areas, are separated by approximately 180 m. The accelerometers were installed within 50 m of the two stope faces as illustrated in Figure 6.

The upper bandwidth limit of the accelerometer is around 1 KHz. The dynamic range of the 8 G accelerometers is suitable for the recording of small seismic events. The captured waveforms are sampled at 4 KHz.

An additional objective of the project is to observe closure of the rock mass and the related micro fracturing of the mining area close to the stope face. To achieve these overall objectives, two technical advances had to be developed. Firstly, close to real time duplex communication from the stope area to surface. Secondly, common time between the closure meters and the associated accelerometer in stope wireless communication was successfully designed and implemented. In addition, duplex communication between surface and the underground in-stope hardware was also successfully developed. This development facilitated a common time stamp between the closure and accelerometer equipment.

A third objective achieved was to design a tri-axial accelerometer sensor array that can fit into a mining stope 'jumper hole.' Traditionally tri-axial sensor arrays are installed in expensive NX (76 mm) diamond drill holes. The development of small tri-axial sensor array is a huge saving on drilling costs

The closure data is visualised on an intranet Grafana graphical display on surface. The display is updated every ten seconds with the latest data from underground.



Figure 4. The 8 G accelerometers.



Figure 5. The installation of the 8 G accelerometer.

Underground Laboratory areas – Masikhane 38 21 & 40 21

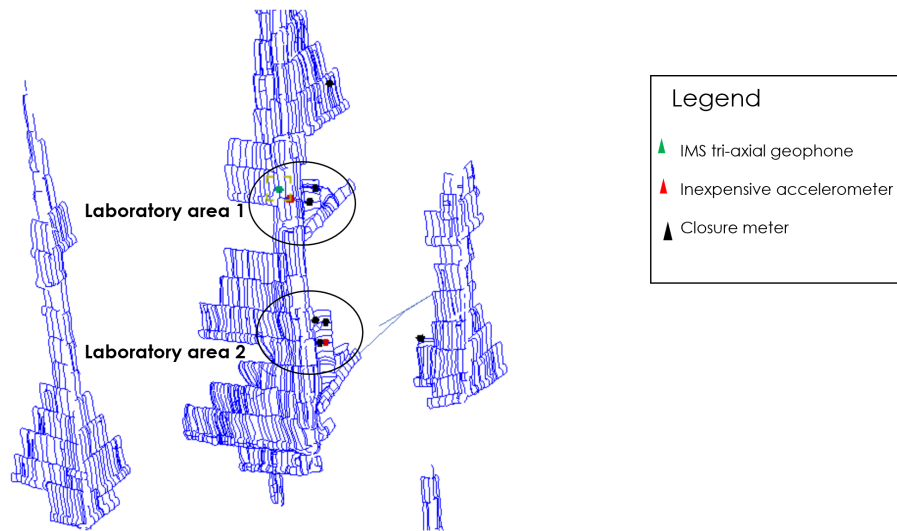


Figure 6. The accelerometers were installed within 50 m of the two stope faces.

Data Flow and Real-Time Monitoring

The communication is described with the aid of Figure 7.

The communication can be divided between two main areas. The first being the existing mine infrastructure going from surface to all levels. This communication medium of normally TCP/IP has a speed of at least 1 Gb/s, although for closure meters speeds much lower are required. The shaft communication link is connected to the stope area by means of a copper cable. This cable is terminated by a power source servicing an in-stope winch. Both ends of the cable are serviced by two Dslam modems. The shaft Dslam modem connects the copper cable to the shaft mine communication infrastructure. In the stope area the Dslam modem interfaces the copper cable to the 8 G accelerometer data logger, and the wireless access point for the closure instrumentation.

The second communication link connects the wireless access point to the closure meters via the gateway as described below.

8 G accelerometer in stope network

The 8 G accelerometer is installed in a jumper hole drilled in the hanging wall. This type of hole is easily drilled in a stope using a conventional stope drill. The accelerometer is connected to the data logger via a thin copper cable.

The in-stope closure meter network

The wireless access point (AP) communicates to the shaft via the Dslam modem for upstream communication. The AP communicates wirelessly to the Gateway (GW) via its own onboard local Wi-Fi. The communication medium used between the GW and the closure meters is LORA. This type of radio frequency communication is suitable for low powered devices and distance for in-stope wireless communication. This is essential in the in-stope areas for conservation of battery consumption located inside the closure meters.

WIRELESS COMMUNICATION DEVELOPMENT COMPLETED EXCLUDING REPEATER

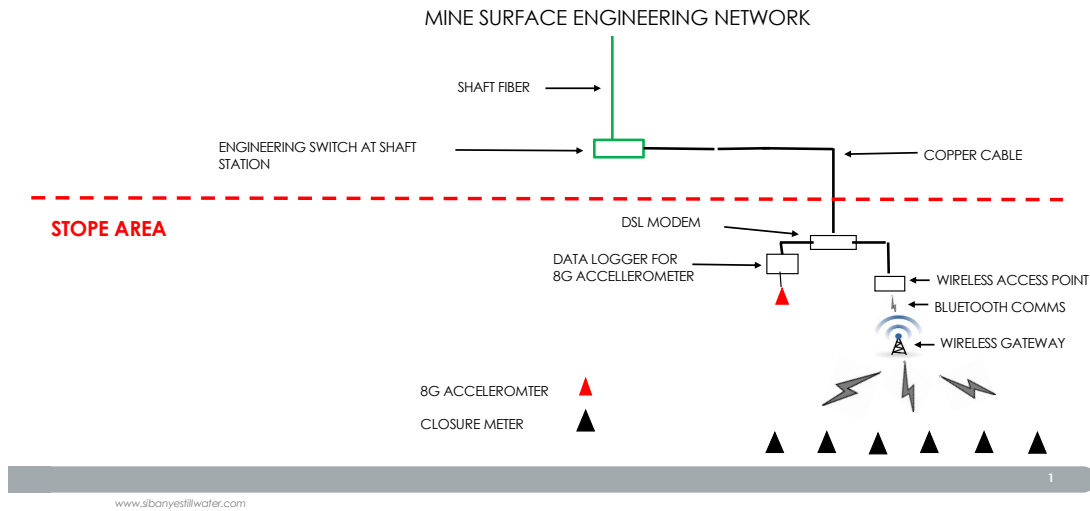


Figure 7. Wireless communication development.

Typical results

From six closure meters

Figure 8 shows typical results obtained with the SmarTrac closure meters over a period of about 16 days. The display is done with Grafana, which gives many viewing options. One or more devices can be selected, time periods zoomed in or out, closure scale and more.

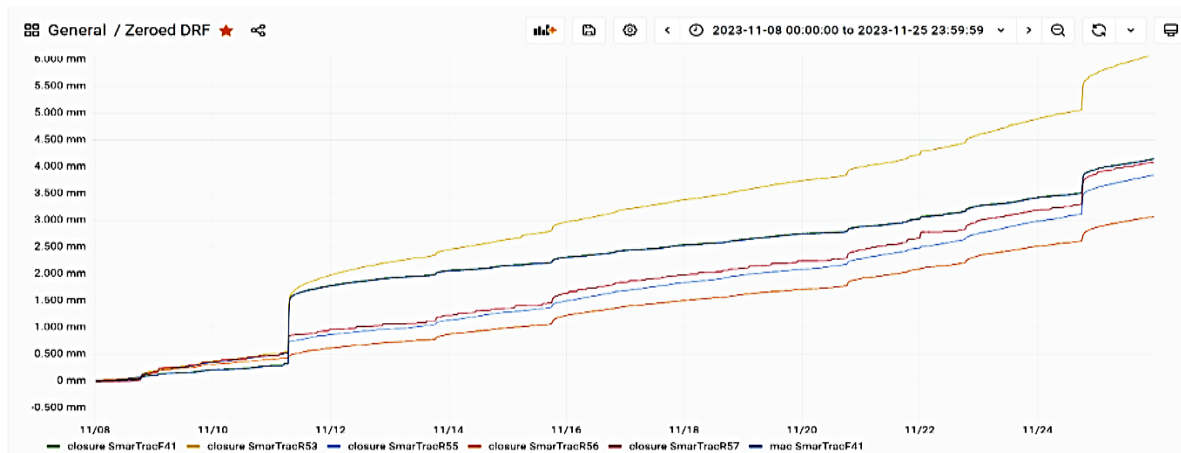


Figure 8. Typical underground closure results from six closure meters over 16 days.

Closure readings over a long period

Figure 9 shows results of a single SmarTrac over the period of about one year. The total closure over this period was only 1.4 mm.

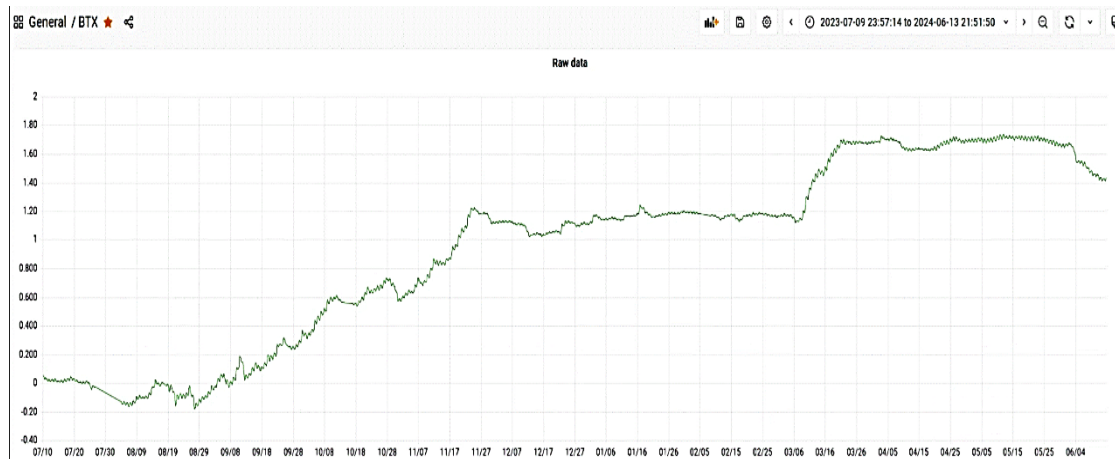


Figure 9. Closure reading for one year.

Closure and extensometer data

Measurements are accurately recorded in real time, allowing for data to be displayed and correlated between different data sources, including closure, accelerometer and extensometer data. Figure 10 shows closure data and extensometer data on the same time scale.

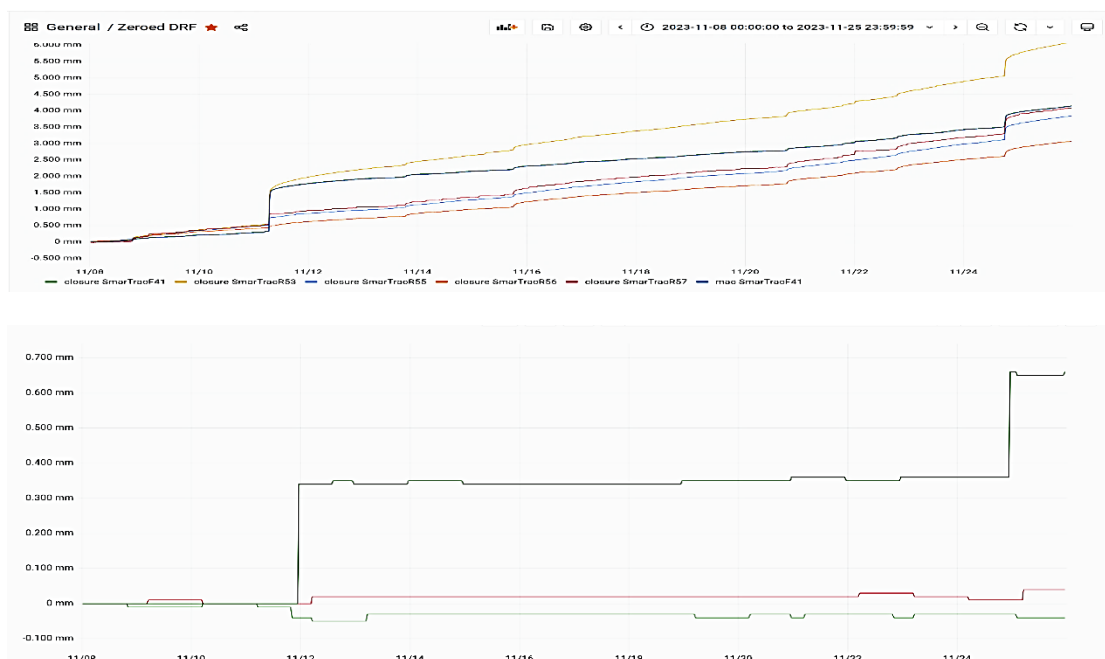


Figure 1. Closure and extensometer data.

Closure after a blast

In Figure 11 the rate of closure in the five hours after the blast can be seen.

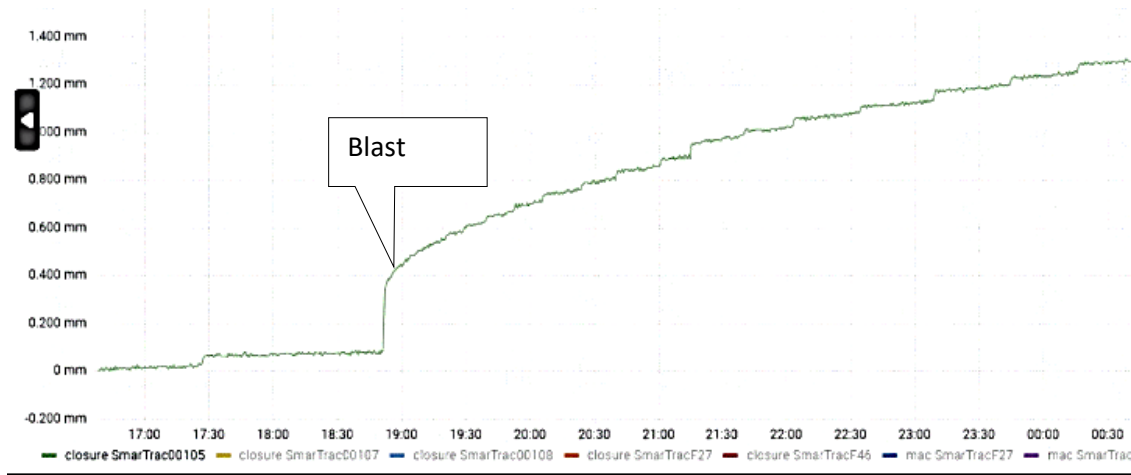


Figure 2. Closure due to a blast.

Example 8 G accelerometer data

The results from the 8 G accelerometer contains a large amount of information, as can be seen in the example in Figure 12.

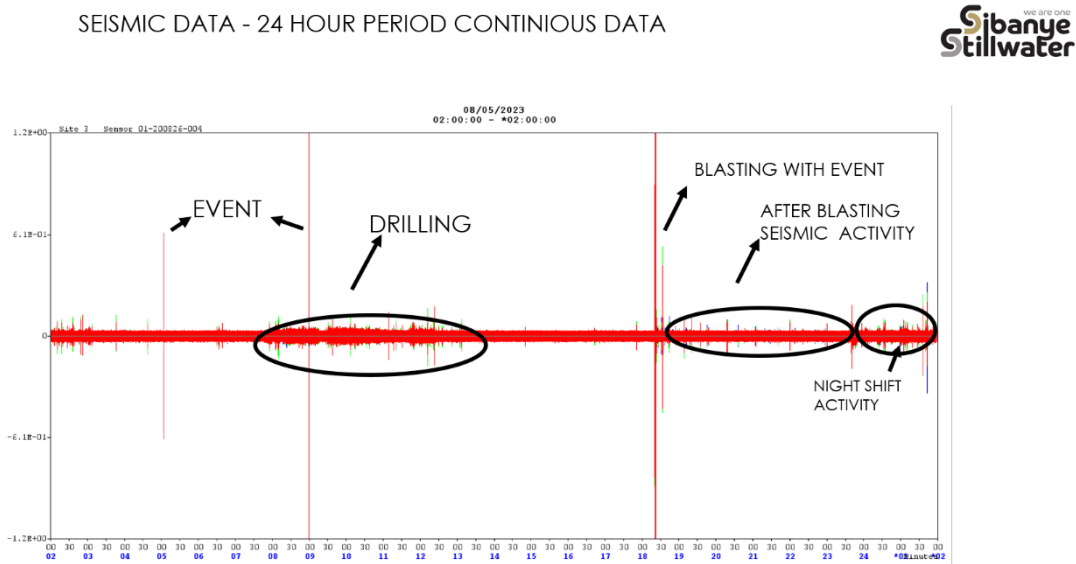


Figure 3. Data recorded with 8 G accelerometer.

Insights from Data Collection

Installations in project area

Figure 13 shows the plan view of the project area. The three red spheres represent large seismic events that occurred on 10 April 2024 close to the stope face where three closure meters (represented by three black dots) and an 8 G accelerometer (red dot) are installed.

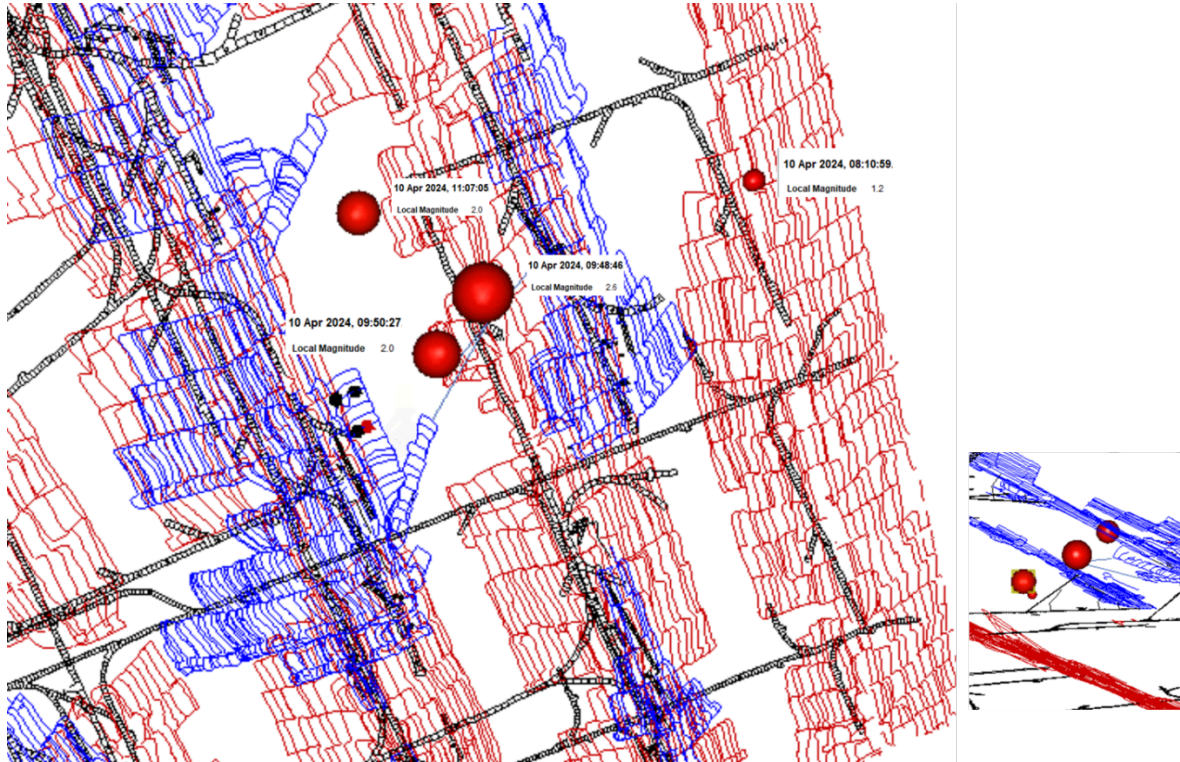


Figure 4. Plan view of the project area and three seismic events occurrences.

Results from instrumentation where seismic events occurred

Figure 14 is a graphical representation of data obtained in a period surrounding the seismic events indicated in Figure 13. The representation shows common time interaction between the 8 G accelerometer data (top section) and the SmarTrac data (bottom section).

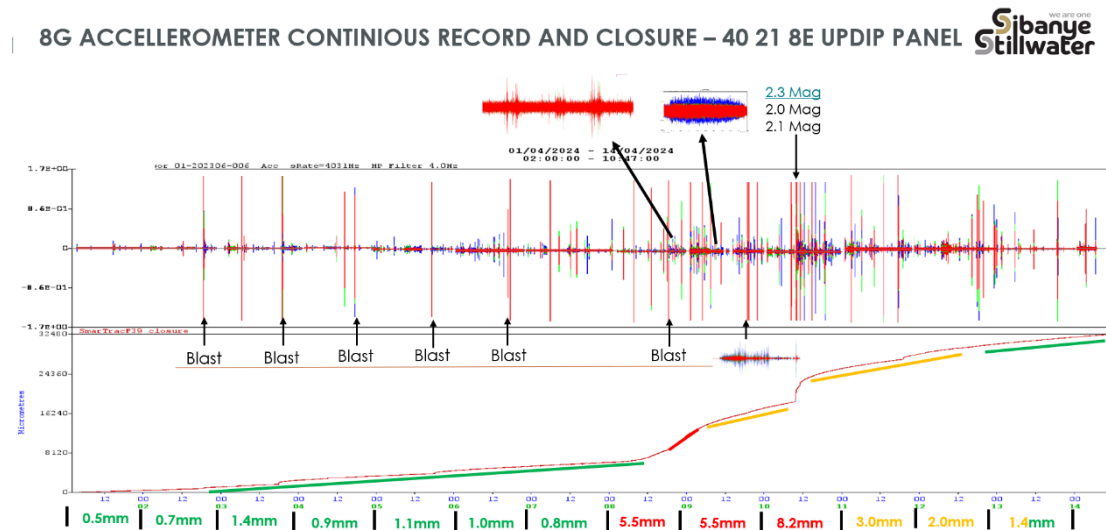


Figure 5. Closure and accelerometer data proceeding large seismic event.

Several interesting and important observations can be made from these results:

- The production blasts are marked in the data. These blasts are on different stope faces within the same mining area. This data is recorded by the 8 G accelerometer.

- The smaller amplitudes between the blasts are small seismic events or fracturing of the rock mass, close to the mining area under observation
- A clear increase in fracturing is observed two days prior to the seismic events.
- The first section of closure (depicted in green) represents normal closure observed in the days prior to the events. Average closure for this period was 0.9 mm per day.
- Two days prior to the seismic events, the closure rate increased to 5.5 mm per day. Strikingly obvious is the associated increase in seismic fracturing during this increased closure period.
- At the time of the events, there is rapid closure resulting in permanent deformation of the rock mass.
- In the three-day period after the events, closure rate remains between 3.0 and 2.0 mm, gradually slowing down.
- After this three-day period, closure rates in the stope revert to normal closure rate observed before the events, at around 1.0 mm per day.

Conclusion

The use of complementary monitoring systems (SmarTrac closure monitoring devices along with the 8 G accelerometer) for the acquisition of relevant rock mass data has demonstrated some interesting results that correlate stope closure patterns with rock fracturing that further resulted in a sequence of seismic activity close to the stoping horizon.

Viewing the continuous closure data with continuous recording (seismograms) from the accelerometer on the same time scale adds significant insight into the rockmass response to mining. In one case study, the rate of closure and fracturing increased significantly prior to a seismic response of three large events ($M_L > 2.0$) near the stopes where the instruments have been installed.

More research is required in this area, but initial results are very encouraging, with the end possibility being that warning can be given for an increased likelihood for large seismic events in a specific area, with the resultant increase in safety for mine employees.

For further consideration:

- Deploying multiple closure meters across a significant area of the mine yields fascinating insights.
- Blasting effects become quantifiable. By analysing closure data before and after blasts, we can assess their impact on mine stability.
- Seismicity, another critical factor, can also be studied. By correlating closure variations with seismic events, we gain a deeper understanding of safety risks.
- The challenge lies in aggregating sufficient data to predict unsafe situations reliably. Our ongoing research aims to address this challenge.

In summary, comprehensive data collection using instruments like the SmarTrac and 8 G accelerometers, empowers mine safety professionals to make informed decisions. By leveraging real-time insights, we move closer to a safer mining environment.

Lourens Scheepers

Patrick Lenegan

Frans Pienaar

Hanno

Hoogenboezem

National NDip

BSc Eng (Civil)

Electrical Engineering Meng (Structures)

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Lourens Johannes Scheepers

Manager Rock Engineering
SibanyeStillwater

27 years in the mining industry, all in deep level gold mines, in the rock engineering departments of Vaal Reefs, AngloGold Ashanti and SibanyeStillwater. Career focussed on the management of seismic risk and presented papers on the rock engineering aspects of mine seismicity.

Enhancing continuous risk management through integration with critical control management plans

A. Boaduo

Gold Fields, South Africa

In the mining industry, effective risk management is essential for safety and minimising health hazards. At South Deep Mine, a three-layered risk assessment strategy was developed, focusing on baseline, issue-based, and continuous risk assessments. Recognising the need for a more practical tool, South Deep Mine replaced traditional pre-work risk assessments with the SLAMM (Stop, Look, Assess, Manage, Monitor) tool in 2019. SLAMM aligns with the Critical Control Management Plan (CCMP), embedding risk management into daily tasks. However, usability challenges with SLAMM Version 3, identified through internal audits and stakeholder feedback, highlighted the need for a more intuitive and engaging tool. Consequently, SLAMM Version 4 was developed, emphasising user engagement, critical control identification, and a seamless digital integration process. This paper examines the development and implementation of SLAMM Version 4, following the ADKAR change management model to ensure smooth adoption and sustainability. The new version aims to foster a culture of proactive risk management by equipping employees to better identify and manage hazards, thus contributing to the mine's continuous safety improvements. The evolution towards full digitisation of the SLAMM process is also discussed, highlighting its potential to provide real-time data analysis and enhance overall safety performance.

Keywords: Continuous risk management, SLAMM tool, Critical Control Management, Material Unwanted Events, mining safety, risk assessment, digital integration.

INTRODUCTION

In the mining industry, continuous risk management is a vital process for maintaining safety and minimising health hazards. At South Deep Mine, an integrated approach to risk assessment has been developed to ensure proactive management of potential risks. The mine employs a comprehensive three-layered risk assessment strategy comprising baseline risk assessment, issue-based risk assessment enhanced by bowtie analysis, and continuous risk assessment. Of these, continuous risk management is particularly emphasised as it involves daily assessments by front-line workers and supervisors, integrating safety into routine operations.

Recognising the need for more effective and focused risk assessments, South Deep Mine transitioned from traditional pre-work risk assessments to the SLAMM (Stop, Look, Assess, Manage, Monitor) tool in 2019. SLAMM, designed to align with the mine's Critical Control Management Plan (CCMP), provides a structured approach for identifying and mitigating risks directly at the workplace. Despite improvements with SLAMM Version 3, feedback from internal audits and employee engagement sessions highlighted usability challenges and a lack of critical engagement, prompting the development of SLAMM Version 4. This paper examines the evolution of SLAMM from Version 3 to Version 4, detailing its alignment with the CCMP, the enhancements made to improve user engagement and risk management practices, and the steps toward digital integration to support a more proactive safety culture.

Background

South Deep Gold Mine is located approximately 45 km west of Johannesburg in the Gauteng Province, spanning 3563 hectares. The mine primarily produces gold, with minor quantities of silver and uranium extracted from its underground orebody using fully mechanised mining methods, including horizontal de-stress mining and long hole stoping. Access to the mine's workings is through two shaft systems: the Twin Shaft Complex, which extends to a depth of

2998 m, and the East Mine Complex, a sub-vertical system reaching a depth of 2786 m. With a workforce of about 5000 employees, nearly half of whom are contractors, South Deep Mine complies with the Mine Health and Safety Act by adopting the Gold Fields Enterprise Risk Framework. This framework integrates strategic risk management with operational hazard identification and risk assessment. The effectiveness of this risk framework, along with other safety initiatives, is evident in the steady decline of total recordable injuries at South Deep Mine, decreasing from 247 in 2012 to just 33 in 2024. (South Deep Mine -a, 2024) (Gold Fields, 2023).

Evolution of SLAMM at South Deep

In 2019, South Deep Mine recognised that its existing pre-work risk assessments were not sufficiently detailed for managing the complex risk scenarios present in the operation. Consequently, the mine introduced the SLAMM tool, designed to enhance continuous risk management by embedding risk assessment directly into daily tasks. SLAMM aligns with the operational CCMP to ensure that critical controls are systematically applied and adhered to across all activities.

Over time, the SLAMM tool has undergone three significant revisions. Each revision aimed to simplify the tool, make it more intuitive for users, and effectively prompt employees to apply the correct critical controls during their tasks. Additionally, the evolution of SLAMM included a digitisation component, where SLAMM documents are scanned and converted into Optical Character Recognition (OCR) format. This digitised data is routed to a Structured Query Language (SQL) database designed to store, analyse, and report on SLAMM assessments. This approach provides stakeholders with a comprehensive overview of the mine's continuous risk assessments, enhancing transparency and supporting data-driven decision-making. Figure 1 illustrates the SLAMM information displayed on the mine's digital dashboard, showing real-time data on risk management activities.

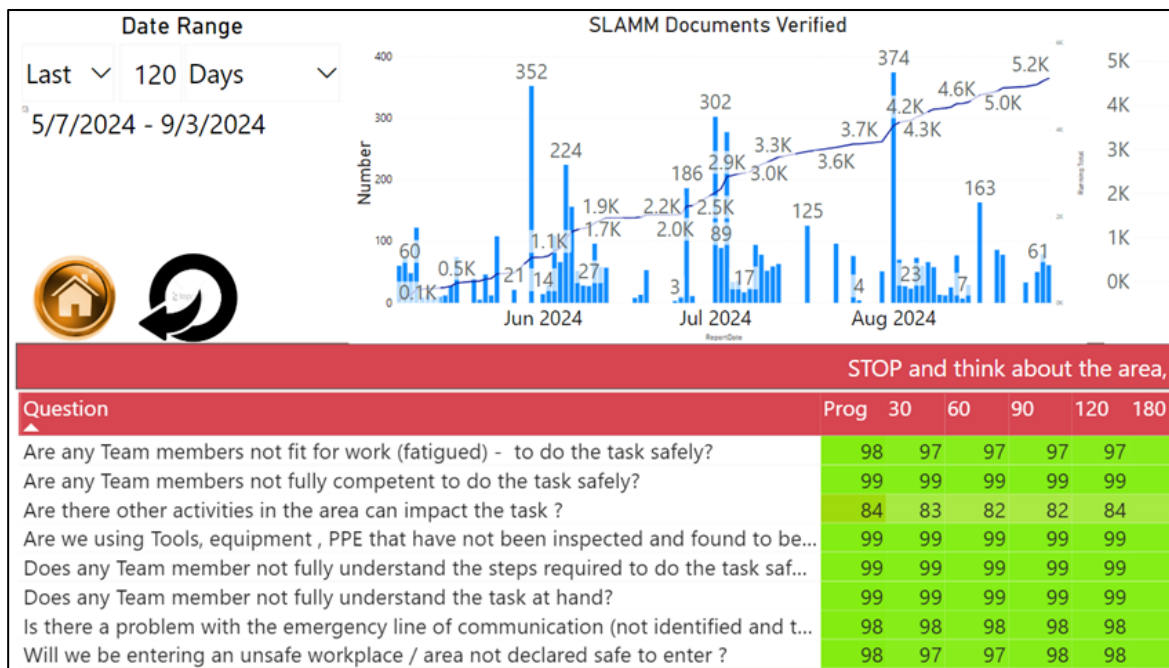


Figure 1. Digital display of SLAMM data.

Rationale behind the development of SLAMM Version 4

During the 2023 Purposeful Visible Felt Leadership sessions and the South Deep Safety Summit, employees and stakeholders raised several concerns about SLAMM Version 3. Feedback from internal and external audits identified key gaps, such as the tool's complexity, lack of user-friendliness, and a 'tick-box' approach that hindered critical thinking and engagement. These issues suggested that SLAMM was being treated more as a bureaucratic exercise than a life-saving tool. To address these issues, the safety department conducted a comprehensive survey of all employees, receiving 363 responses. This was the first time South Deep had formally engaged SLAMM users to obtain their feedback and buy-in regarding the tool's use and effectiveness. The survey results clearly indicated the need for a more intuitive tool that fosters active participation and a deeper understanding of risk management. Figure 2 outlines the suggestions gathered from the survey, which guided the development of a more effective and user-friendly SLAMM Version 4.

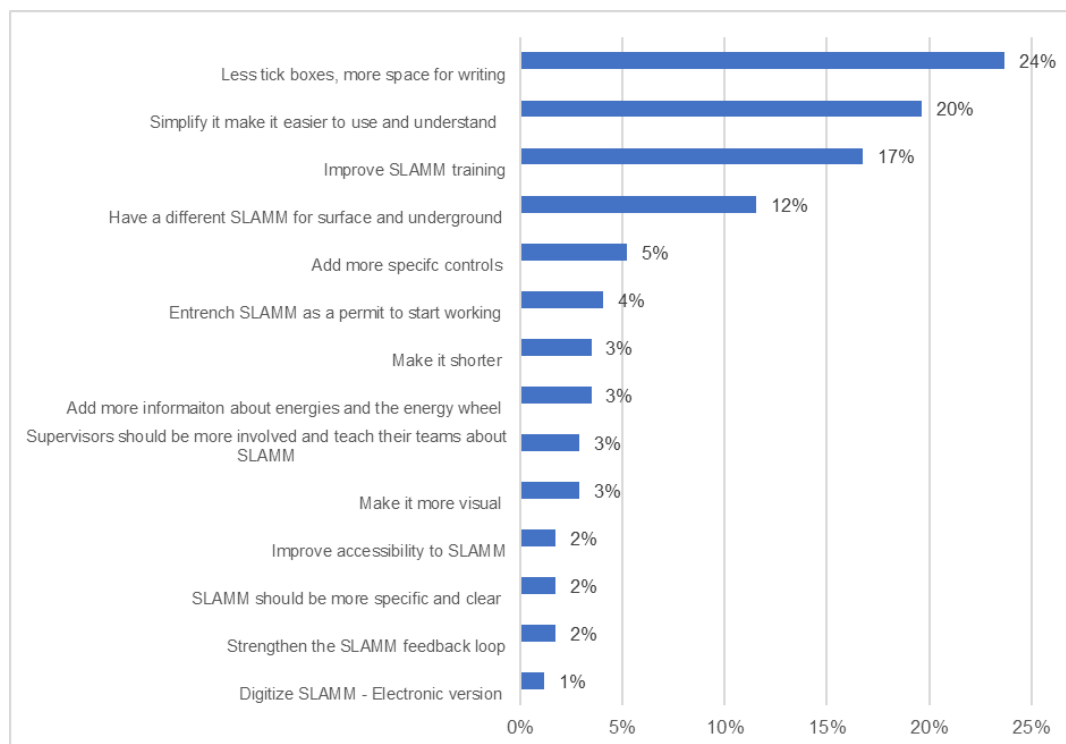


Figure 2. Suggestions made for the improvement of SLAMM.

Development of SLAMM Version 4

SLAMM Version 4 was developed to address stakeholder feedback and to better align the continuous risk assessment process with the CCMP. The goal was to create a tool that not only meets practical safety needs but also fosters meaningful discussions about safety behaviours among team members. The updated version prompts employees to identify Material Unwanted Events (MUEs), associated energies, and potential hazards specific to their tasks. It further encourages them to detail the critical behaviours necessary to manage these MUEs and carry out their tasks safely.

To ensure a smooth transition and effective adoption, SLAMM Version 4 was developed following the ADKAR change management model, which focuses on building Awareness, creating Desire, imparting Knowledge, enhancing Ability, and ensuring Reinforcement. This structured approach was key in addressing the concerns raised by stakeholders and integrating the new version seamlessly into daily operations. By targeting these elements, SLAMM Version 4 aims to cultivate a more engaged workforce that is better prepared to identify, assess, and manage risks, thereby reinforcing a culture of safety excellence at South Deep Mine.

The table below outlines how each ADKAR element was applied during the development and implementation of SLAMM Version 4, highlighting the objectives, activities, and strategies for each stakeholder group.

Table I. Application of ADKAR element in the development of the SLAMM

ADKAR Element	Objective	Activities	Application
Awareness	Ensure all stakeholders understand the need for SLAMM Version 4 and the reasons for its development.	Conduct awareness sessions for frontline employees, line supervisors, safety and training departments, and senior management. Highlight gaps in SLAMM Version 3 and how Version 4 addresses these.	Communicate benefits such as better alignment with the CCMP, improved identification of MUEs, and a more user-friendly tool. Use visual aids, real-life examples, and case studies.
Desire	Foster a desire among all stakeholders to embrace and support SLAMM Version 4.	Engage employees in discussions on how SLAMM Version 4 aligns with their safety concerns and work practices. Encourage ownership and active participation.	Highlight the impact of SLAMM Version 4 on safety outcomes, empowering employees to manage risks more effectively. Recognise early adopters and success stories to build momentum.
Knowledge	Ensure employees have the knowledge needed to use SLAMM Version 4 effectively.	Provide comprehensive training sessions on SLAMM Version 4's use, including workshops, manuals, and virtual training.	Train employees on the identification of MUEs, the correct application of critical controls, and effective communication of risks. Provide practical examples to reinforce learning.
Ability	Equip stakeholders with the skills and resources to implement SLAMM Version 4 confidently.	Conduct hands-on workshops, simulations, and scenario-based training sessions to practice using SLAMM Version 4 in real-world settings.	Provide guidance and support during the initial implementation phase. Offer access to expert assistance to address any challenges encountered by employees.
Reinforcement	Ensure that SLAMM Version 4 becomes a sustained part of the safety culture at South Deep Mine.	Establish feedback mechanisms, performance metrics, and recognition programs to reinforce the use of SLAMM Version 4. Integrate SLAMM practices into safety evaluations.	Regularly communicate SLAMM performance data to stakeholders. Recognise and reward teams that effectively utilise the tool, reinforcing its importance in achieving zero harm.

Closing the Loop – Providing Actionable Feedback

One of the major weaknesses identified in previous SLAMM versions was the lack of an effective feedback loop, which limited opportunities for continuous improvement. To resolve this, a robust feedback mechanism has been developed for SLAMM Version 4, targeting senior managers, line supervisors, and end users. Monthly SLAMM activity reports will provide data on the number of SLAMMs conducted, the quality of assessments, and insights into task-specific risks. Additionally, analyses of MUEs, energy identification, and task alignment will help identify safety training gaps and opportunities for improvement. Integrating these feedback loops into the SLAMM process will ensure that all stakeholders are informed and engaged in enhancing safety practices.

Advancing Towards Complete Digitisation of the SLAMM Process

Currently, the SLAMM process at South Deep Mine remains only partially digitised, as it still relies heavily on manual data capture by the safety department. Once SLAMMs are completed and verified, they must be manually scanned and converted into OCR format for further processing – a method prone to delays and errors. To optimise this process, South Deep Mine aims to achieve full digitisation by equipping employees involved in the continuous risk assessment process with digital safety devices. This initiative will allow employees to capture SLAMMs directly on these devices, which would then automatically upload the data to the information management platform. This streamlined approach would eliminate manual handling, reduce errors, and enhance data accuracy. Fully digitising the SLAMM process will also enable real-time data analysis, providing stakeholders with immediate insights into safety performance and substantially improving the overall effectiveness of risk management.

CONCLUSION

The evolution of the SLAMM document at South Deep Mine offers valuable insights for the South African mining industry on how to effectively integrate continuous risk management into daily operations. Key learnings from this development process highlight the importance of aligning safety tools with practical needs on the ground, fostering a culture of active engagement among employees, and leveraging feedback to drive meaningful improvements. By moving away from traditional, checklist-driven risk assessments to a more dynamic and user-centric tool, South Deep has demonstrated how continuous risk management can be transformed into a proactive, life-saving practice rather than a bureaucratic formality.

For the South African mining industry, the experience with SLAMM Version 4 underscores several critical takeaways. Firstly, engaging frontline workers in safety management by incorporating their feedback can significantly enhance the relevance and effectiveness of safety tools. Secondly, the alignment of risk management practices with broader safety initiatives, such as the CCMP, ensures a more cohesive approach to managing workplace hazards. Thirdly, adopting a structured change management approach, such as the ADKAR model, is essential to successfully roll out new safety initiatives, ensuring buy-in at all levels of the organisation.

Looking ahead, the industry's focus should also be on harnessing digital technologies to streamline safety processes, reduce manual data entry errors, and provide real-time insights for decision-making. Full digitisation of tools like SLAMM could significantly enhance data accuracy, speed up feedback loops, and empower stakeholders with actionable information. By embracing these strategies, the South African mining industry can move closer to its goal of Zero Harm, setting a global standard for safety and risk management excellence.

ACKNOWLEDGEMENTS

The author extends sincere gratitude to Jacques Erasmus, Head of Safety at South Deep Mine, for his invaluable support and guidance in developing this paper. His commitment to enhancing safety and continuous improvement has been instrumental in shaping the evolution of SLAMM Version 4 and advancing risk management practices at South Deep Mine.

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Dr Adwoa Boaduo

Unit Manager - Safety
Gold Fields

Dr. Adwoa Boaduo is a mining engineer with over 14 years of operational experience, specializing in mine safety and geotechnical engineering. Over the past nine years, she has conducted impactful research on mineral-based sustainable development, aligning her technical expertise with a commitment to safe, responsible mining practices. Dr. Boaduo's unique ability to bridge practical mining operations with sustainability initiatives has positioned her as a key contributor to advancing safe and sustainable practices in the industry.

Cannabis use and its impact on health and safety in the South African mining industry

N. Tlotleng^{1,2,3}, Z. Nkosi¹, and F. Magweregwe¹

¹Mine Health and Safety Council, South Africa

²University of Pretoria, South Africa

³University of the Witwatersrand, South Africa

Cannabis sativa or cannabis referred to as marijuana, hemp, dagga, mbanje or chamba contains the psychoactive compound Δ^9 - tetrahydrocannabinol (THC) which is reported to have short-term health benefits. For medicinal uses, cannabis reduces chronic body pains, severe nausea and vomiting, epilepsy, seizures, depression, anxiety, and sleep disorders. For leisure use, cannabis creates a feeling of relaxation, happiness, and mood enhancement. In physically demanding occupations, such as mining, cannabis has been used to enhance performance as an energy booster. In South Africa and many other countries, cannabis has been legalised for recreational use. Nonetheless, this legalisation does not provide clear guidance on the management of cannabis and its impact on occupational health and safety (OHS). Studies have reported adverse effects on workplace safety and productivity in employees who use cannabis (Kornpointner et al., 2021; Carnide et al., 2023; Hinton & Asher, 2022). Therefore, in high-risk occupations such as mining, clear guidance on cannabis management is needed. In this paper, we assessed the knowledge and perception of key stakeholders in the South African Mining Industry (SAMI) on cannabis decriminalisation and its impact on workplace health, safety, and productivity.

METHODS

A questionnaire was used to collect the information required to understand the stakeholders' perspectives on cannabis decriminalisation and its impact on OHS and productivity in the workplace. The survey gathered information to assess if there was enough awareness and training on cannabis in the SAMI, and whether drug policies, substance assessment tools and procedures in mining operations and employment policies had been revised since cannabis was decriminalised in South Africa.

RESULTS

The majority of participants who responded to the survey were from mining companies (70%, n=149), with representatives from mineworkers (20%, n=41), followed by middle managers (18%, n=38), occupational health practitioners (16%, n=33), production supervisors (11%, n=23), mine overseers (11%, n=22), occupational medical practitioners (10%, n=20), senior managers (10%, n=21), executive manager (3%, n=7) and organisation spokesperson (1%, n=3). About 89% (n=187/209) of survey participants were aware of cannabis decriminalisation, and 54% agreed that the use of cannabis has negative implications for OHS in the SAMI. The majority of participants (47%) who were middle managers and occupational health practitioners indicated that the number of accidents and incidents had remained the same since cannabis was legalised and indicated that existing drug testing and assessment procedures implemented in the SAMI had not been revised since cannabis was decriminalised.

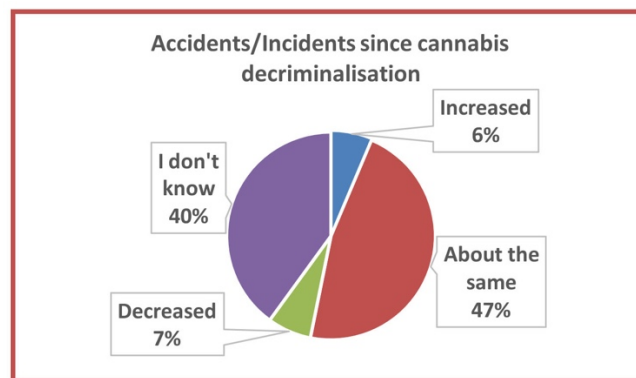


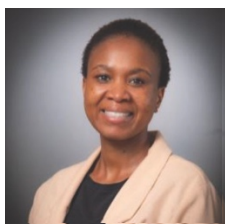
Figure 1. Stakeholders' perception on accidents since cannabis decriminalisation.

CONCLUSION

Overall, from the information collected and from the stakeholder engagements, it was evident that employees who test positive for cannabis use in the mines should not be allowed to proceed with their daily tasks. In addition, it was proposed that cannabis should be managed in the same manner as other drugs and alcohol in workplaces, indicating a zero-tolerance approach to its use in the SAMI.

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Nonhlanhla Tlotleng

Occupational Health Research Specialist
Mine Health and Safety Council

Dr. Nonhlanhla Tlotleng is an Occupational Health Research Specialist within the Centre of Excellence at the Mine Health and Safety Council. Dr. Tlotleng is an NRF rated Public Health Researcher and an Epidemiologist with over ten years research experience in Occupational Health. She has published widely in Occupational Health, including reviews and books pertaining to workplace hazards and their adverse health effects. She is a member of the editorial board for several peer review journals serving as a reviewer and an academic Editor. Affiliated with several universities, Dr. Tlotleng is involved in teaching, training and supervision of postgraduate students in Public Health. She holds a Bachelor's degree and a Masters in Biotechnology from the University of Johannesburg, and she further completed an MSc degree in Epidemiology and a PhD, both from the University of the Witwatersrand.

Fraser Alexander tailings division's journey towards zero harm – A case study

S.M. Thema

Tailings and Remining, South Africa

INTRODUCTION

Achieving Zero Harm remains one of the mining industry's most desired milestones, and although this is achievable, current safety performance suggests that more work needs to be done to prevent the occurrence of incidents and injuries. Figure 1 indicates the total fatalities and the fatalities per classification in the South African mining industry (SAMI) over the last two decades. The SAMI registered a fivefold decrease from 270 in 2003 to 55 fatalities in 2023. A record low of 49 fatalities in 2022 was recorded, and although this indicated a significant milestone, it is generally accepted by all stakeholders in the mining industry that one fatality is one too many. Although this improvement is welcome, one life lost, is one too many! The journey towards Zero Harm continues.

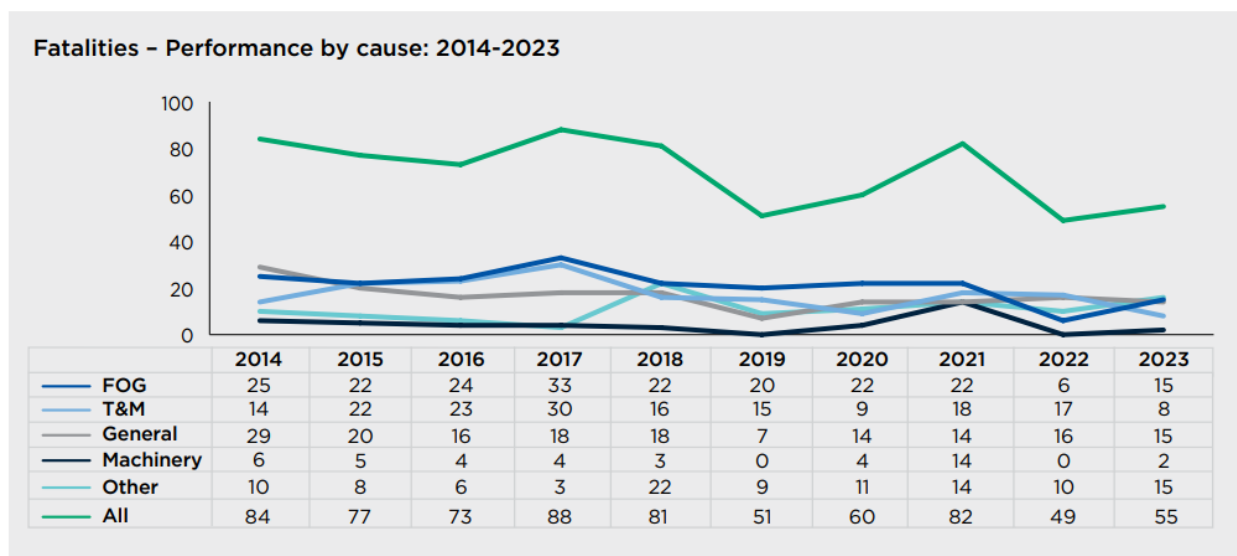


Figure 1. South African mining industry fatal injuries trends 2003 to 2023 (Minerals Council, 2024)

Fraser Alexander (FA)'s tailings and remining division in South Africa has a workforce of approximately 1800 employees spread over 60 sites across the length and breadth of the SAMI. The division last reported a fatal injury in 2018 and has since had a 5 years fatality-free period as shown in Figure 2. The significant turn-around in the safety performance of the division was backed by executive leadership and management commitment, and measures put in place to align the business operations towards becoming a fatality-free business.

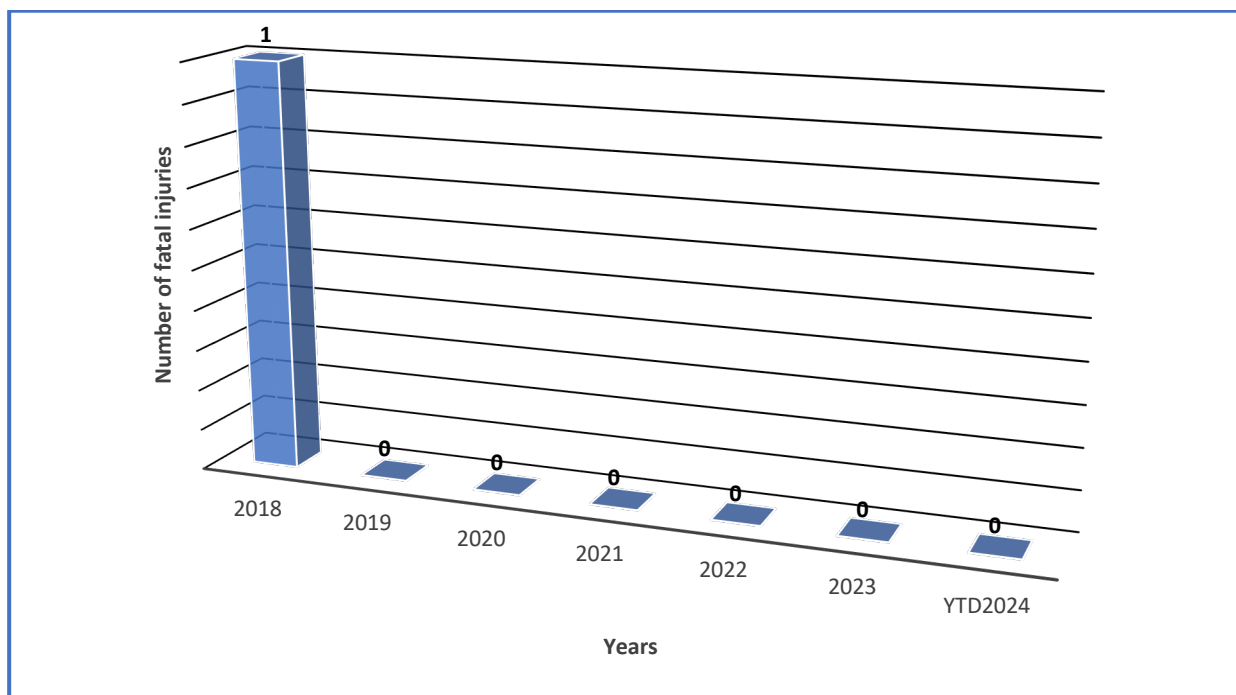


Figure 2. Fraser Alexander Tailings Division fatal injury trends since 2018.

Fraser Alexander Zero Harm Framework

One of the key interventions in FA's zero harm journey was the introduction of the Zero Harm Framework, which was founded on four pillars of leadership commitment: risk and change management, learning from incidents, planning and scheduling, and monitoring and assurance. The Fraser Alexander Zero Harm Framework is shown in Figure 3.

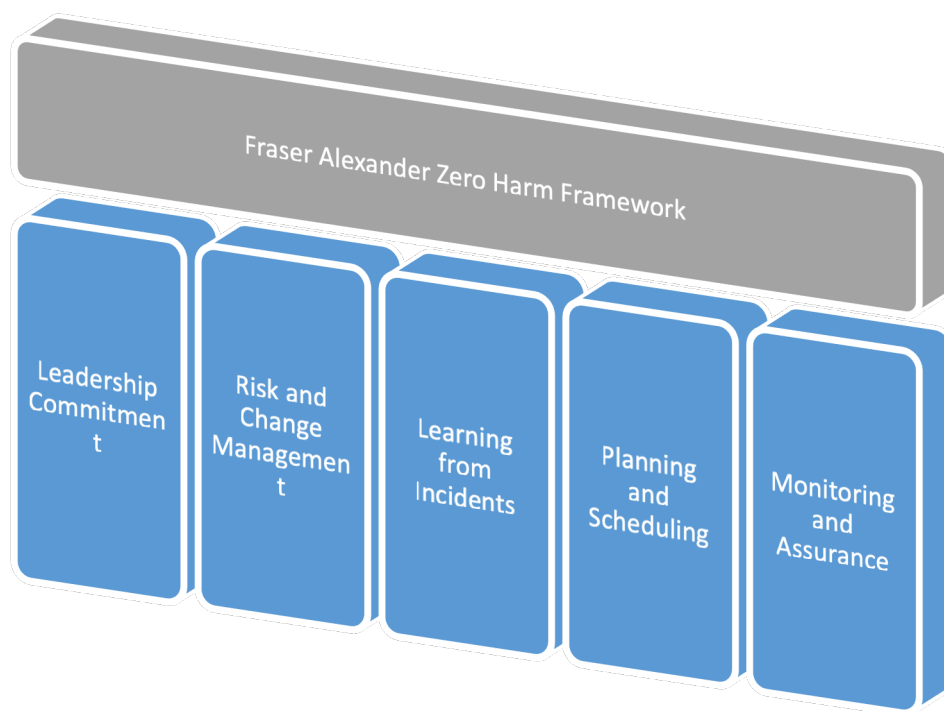


Figure 3. Fraser Alexander Zero Harm Framework

The details of the contents of each of the five pillars of the Fraser Alexander Zero harm Framework are summarised below:

1. The first pillar of leadership commitment in the framework refers to the top-down commitment from the Board of Directors, Executive Committee, Management Committee to supervisory and lower-level employees to achieve a safe day at work for all to return home safely to their loved ones.
2. The second pillar refers to the process of managing risks from baseline to continuous risk management. This pillar also includes the process of change management which is often associated with issue-based risk management.
3. Pillar three refers to inculcating a culture of learning from incidents and ensuring that repeat incidents are prevented.
4. Pillar four refers to the need to ensure good planning and scheduling of work, ensuring that the plan is well understood, and the required resources are available for safe execution.
5. The fifth and last pillar refers to ensuring that there is consistent monitoring and quality assurance of work being conducted. This includes deploying the services of independent third parties to review performance.

The framework was developed and introduced in the year 2021 and had a significant impact in reducing safety related injuries in the last three years as shown in Figure 4.

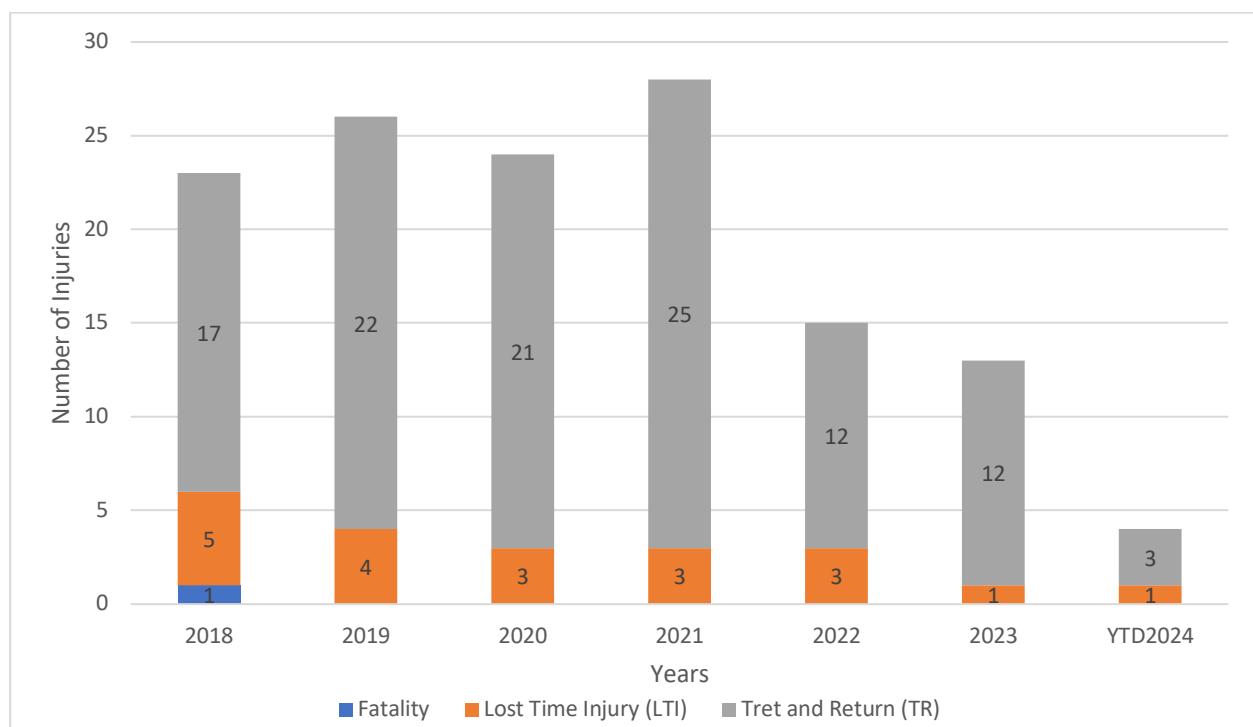


Figure 4. Fraser Alexander Tailings Division injury trends 2018 to 2024 YTD.

CONCLUSION

The presentation will provide more details of how the significant milestones in safety were achieved at Fraser Alexander Tailings Division, including how the Zero Harm framework continues to be used to sustain a culture of continuous improvement. Various tools including the FA safety management system; leading and lagging indicators and independent audits and surveys are used to try and proactively prevent incidents and injuries.

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Sephela Makete Thema

General Manager: Tailings and Remining South Africa
Fraser Alexander

Sephela Makete Thema is an experienced mining sustainability executive employed as General Manager for Tailings and Remining at Fraser Alexander, and responsible for the South African and Namibian operations. He leads a team of 1800 members that is spread across sixty-seven (67) operational sites within South Africa and Namibia. Makete has worked for several blue-chip companies in the mining industry in the past 13 years and went through the ranks from mining graduate, Shiftboss, Mine Overseer, Mine Manager, VP and Head of Operations to his current role of General Manager.

Makete is a professional member of the Southern Africa Institute of Mining and Metallurgy (SAIMM) and serves on the SAIMM Young Professionals Council (YPC). Makete is also a member of the Association of Mine Managers of South Africa (AMMSA) and is a registered engineer with the Engineering Council of South Africa (ECSA).

Psychological safety in African Mining

N. Gage

People & Communication, South Africa

The mining industry across Africa faces numerous high-risk challenges where workers' safety, health, and well-being are paramount. As companies transition to reduce harm, psychological safety is not just a buzzword but a critical factor in operational success. While physical safety is a key focus in mining, psychological safety – the belief that one can express ideas, questions, and concerns without fear of negative consequences – is essential in driving safety performance and overall team efficiency. Its importance cannot be overstated, and it is urgent that we give it the attention it deserves.

Psychological safety, which hinges on the belief that speaking up within a team enhances decision-making, cultivates innovation and reduces errors, is a crucial but often overlooked aspect of workplace culture. This is particularly true in high-hazard sectors like mining.

The mining workforce, comprising a diverse mix of employees, contractors, and third parties, often grapples with issues of vulnerability, such as fear of retribution, exclusion, or punishment for errors or speaking up. These issues can stifle communication and deter the reporting of potential hazards or unsafe practices, thereby creating a hazardous work environment. However, by cultivating psychological safety, mining organisations can unlock a host of benefits, including improved decision-making, enhanced speaking up for safety, and reduced errors and incidents. These are not just theoretical benefits but real, tangible outcomes that can significantly improve safe operations and increase performance and productivity.

In African mining, where cultural diversity, complex labour structures, and harsh working conditions converge, the introduction and nurturing of psychological safety are both a challenge and an opportunity. For leaders and safety practitioners, this is a call to action. Understanding and cultivating psychological safety could transform mining organisations' safety culture and operational effectiveness. Leaders have a crucial role in this transformation, and their actions can make a significant difference.

This presentation draws on leading research and will explore how psychological safety can be purposefully shaped within mining environments, emphasising its direct impact on team dynamics and overall safety outcomes.

It will explore how trust between individuals and psychological safety among teams have crucial differences and should be carefully considered when understanding how psychological safety impacts teams.

It will introduce a framework based on four progressive stages: Inclusion Safety, Learner Safety, Contributor Safety, and Challenger Safety.

Inclusion Safety asks - Can I be my authentic self?

Learner Safety asks - Can I Grow?

Contributor Safety asks - Can I Add Value?

Challenger Safety asks - Can I Speak Up?

These stages provide practical steps for leaders to assess and improve psychological safety in their teams. They highlight the importance of encouraging vulnerability and reward systems that allow workers to feel safe expressing concerns, admitting mistakes, and contributing ideas.

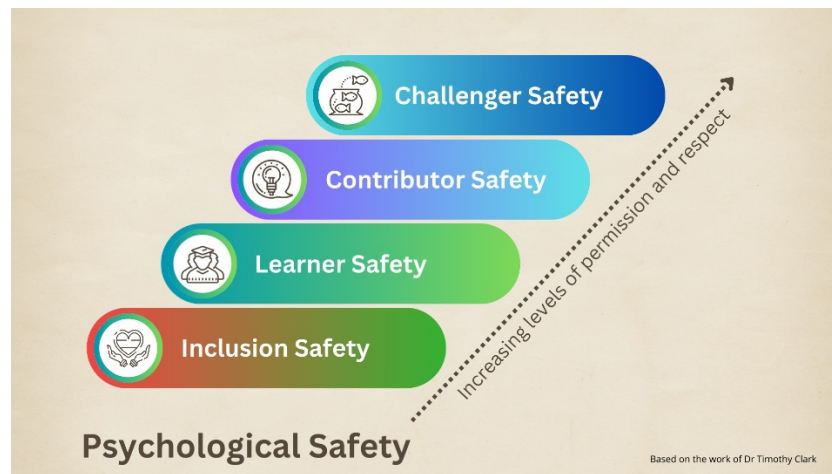


Figure 1. The four stages of psychological safety based on the work of Dr Timothy Clark¹

By enhancing psychological safety, mining organisations can create an environment where employees are more engaged, proactive, and aligned with safety goals.

This paper will provide insights into how cultivating psychological safety aligns with a value-based approach to health and safety and offer practical strategies. These strategies will equip leaders with the tools to develop their capabilities, promote open dialogue, reduce fear, and cultivate a resilient safety culture. The potential benefits are significant, offering a hopeful vision for the future of African mining.

Challenging leaders to consider ‘How do you build Psychological Safety?’ and explore how purposefully shaping your safety culture through psychological safety instead of by default (accident) is a good starting point.

This paper is based on numerous bodies of work, and the Psychological Safety Info Hub² provides a wealth of information supporting the basis for employing psychological safety in your teams.

In conclusion, this paper will call for mining leaders to embrace psychological safety as a critical element in their safety management systems.

By adopting a framework that rewards vulnerability and encourages team engagement, African mining can move closer to achieving operational excellence and its commitment to safeguarding its workforce.

¹<https://www.amazon.com/Stages-Psychological-Safety-Inclusion-Innovation/dp/1523087684>

²<https://safetycollaborations.com/psychological-safety-hub/>



Nuala Gage

Director
Safety Collaborations Ltd

Nuala Gage is the Director of Consulting at Safety Collaborations, with a notable background in advancing safety culture and psychological safety across high-hazard industries worldwide. Her extensive work in sectors like oil & gas, mining, and energy is grounded in a unique approach that blends behavioural safety, leadership coaching, and a practical application of human factors. Nuala's work focuses on building resilient, collaborative teams that embrace safety as a core value, from leadership through to frontline operations. Known for her solutions-oriented style and cultural insight, she partners with organisations to drive meaningful, sustainable improvements in safety and communication.

Critical controls for seismic risk management in deep level gold mines

L. Scheepers

SibanyeStillwater, South Africa

The effective implementation of critical controls is key in delivering on safety targets, but which are the appropriate critical controls for seismic risk management and how are they determined?

In this paper I will list the important critical controls for seismic risk management appropriate to the SibanyeStillwater deep level gold mines and explore how one of the controls, i.e., lead-lag distance has been determined.

Planning is an overarching critical management routine and refers to long-term (LOM and BP), medium-term (three month and monthly) as well as short-term (next shift) planning. Monthly planning for example, being a critical management routine as well as a critical control, may not be interfered with by anyone. The planning dates for the different sections must be determined and scheduled one day after measuring and these meetings must take priority over other activities on the mine – all the service departments must provide appropriate input into the plan. Nearly all safety and production failures can be traced back to insufficient planning.

The monthly plan must make reference to the mining strategy (aligned with the COP) which for our deep level gold mines will have clear rules on the following:

- Mine design
 - Partial extraction with regional stability pillars and limited mining spans
 - Bracket pillars
 - Approach angles
 - Lead-lag
 - Face shape
- Preconditioning
 - Face perpendicular preconditioning
 - Large scale preconditioning (research topic)
- Support design
 - Pre-stressed yielding elongates
 - Packs (gullies)
 - Backfill
 - In-stope bolting
 - Permanent blast-on mesh/nets

Each of these rules are critical controls that are measured and reported on. Where non-compliance is identified, mining must be stopped until the non-compliance has been rectified ('stop and fix').

Consistent improvement in compliance to critical controls, critical management routines and critical safe behaviour leads to consistent improvement in measured safety lagging indicators, even seismic related falls of ground (FOG). In the graph (Figure 1) I extracted seismic related (rockburst and strainburst) FOG serious injury statistics and normalised it to production (number of injuries in a year divided by the square metres mined in that year for our seismically active mines (Kloof and Driefontein). This is representative of the success or failure of the seismic risk management strategy rather than compliance with barring and other safe-making actions impacting on FOG gravity.

The decreasing trend post 2020 is representative of consistent implementation of an improved seismic risk management strategy and improved culture towards compliance with critical controls.

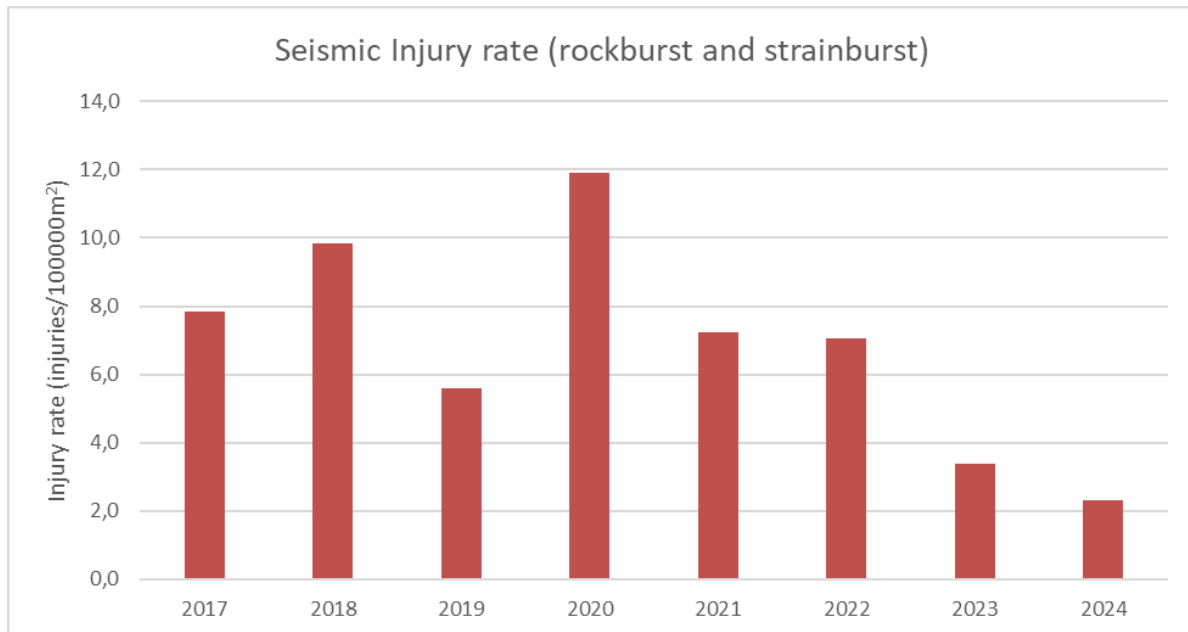


Figure 1. Annual FOG rockburst and strainburst serious injuries normalised with 100000 m² mined.

Lead-lag compliance is one of the critical controls listed and measured on a monthly basis. Lead-lag refers to the distance measured between two adjacent panel faces. The ideal lead-lag is determined during the mine design phase and assigned to each working place during planning.

Typical lead-lag distances of 5 m minimum to 10 m maximum have been defined on many deep level operations. The reason that lead-lag is an important parameter to monitor is that it is linked to a FOG risk as well as a seismic risk. From a FOG risk perspective, the ideal lead-lag would be as small as possible as large lead-lags typically result in flat dipping fractures on the leading abutment in deep level (high stress) mines. Small lead-lags between a number of adjacent panels will result in a long continuous mining abutment. This increases the seismic risk as it tends to promote the occurrence of large abutment related seismic events. From a seismic risk perspective, larger lead-lags are preferred in order to break up the long abutment into smaller portions.

From this discussion it seems that the ideal lead-lag from a FOG perspective may contradict the ideal lead-lag from a seismic risk perspective. So how is the ideal lead-lag then determined?

The process to determine the ideal lead-lag for SibanyeStillwater deep level gold mines:

Seismic risk:

- Geological structures (faults and dykes) in close proximity to mining where they are exposed to stress changes, are well-known sources of seismic events. Specific lead-lag rules/controls are relevant in terms of managing the overall mining approach angle and number of panels exposing the structure at any point in time. The aim is to minimise the area of structure being exposed to stress changes.
- Abutments: Pillar abutments are not controlled by lead-lag rules, but for overall longwall face abutments the seismic risk is increased when the lead/lags are too small. Lead-lag abutments can be considered sources when the lead-lag distances are excessive. Stress concentrations are often associated with lead-lags, and is typically a strata control issue, that is an increased fall of ground risk. This risk must be mitigated with increased support density or area coverage

support. Large lead-lags may occasionally result in an increased strainburst risk and this must be mitigated with preconditioning.

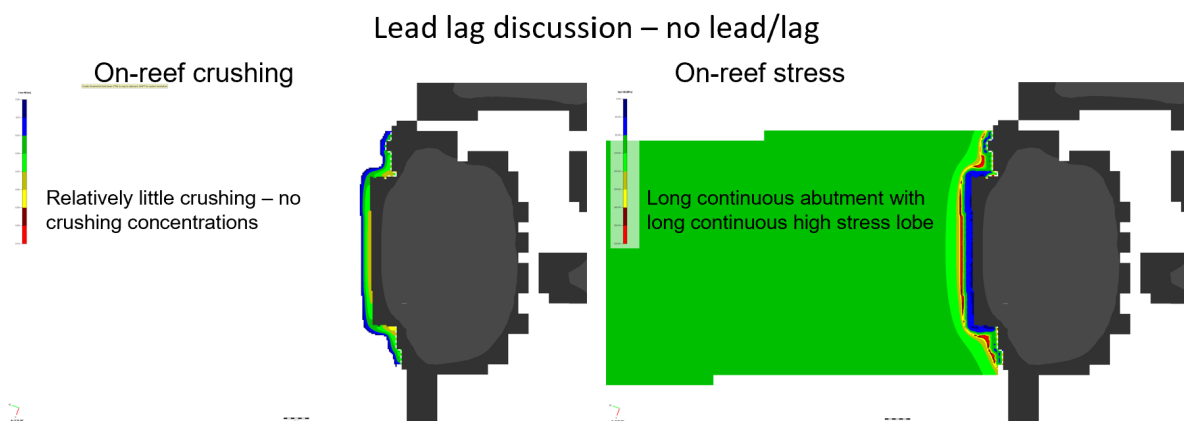
Fall of ground risk:

- Rockmass response to seismicity – several factors may impact on the excavation vulnerability under seismic loading conditions
 - Increased lead-lag increases the length of gully exposed. A deep siding and backfill in the siding mitigates this hazard
 - Increased lead-lags result in cross fracturing and shallow dipping fractures at the toe of the lagging panel, increasing shake-down potential
 - Support reaction – elongate support may have yielded to its limit, but pack support now reacts well. Insufficient area cover between support units.
 - Tipping points choke due to closure and when blasted open between the packs it often destroys the good support reaction of the gully packs. The damaged support must be replaced

Other constraints:

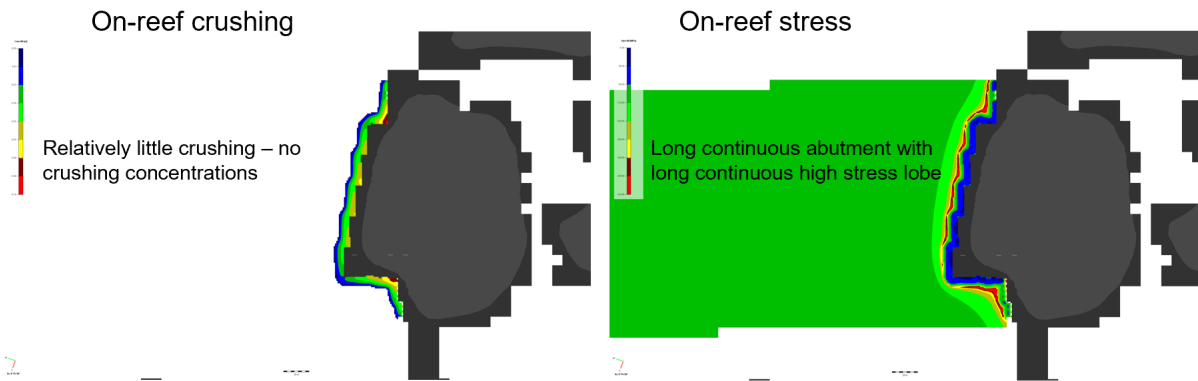
- Ventilation flow is reduced with increasing lead-lags. The biggest issue is the fact that the escape gully is not kept close to the leading face and ventilation is restricted
- Production constraints (cleaning). For the gully winch to be effective, the snatch block needs to be installed with a 3 m overrun. Where there is no lead-lag, there is no overrun and this leads to difficult cleaning. This situation is improved with increasing lead-lag but deteriorates again with excessive lead-lags.

Lead-lag discussion modelling insight

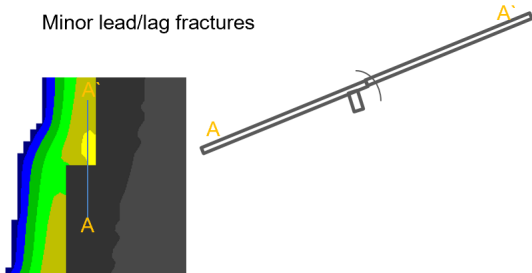


- No lead/lag fractures
- potential for large event with damage to multiple panels

Lead lag discussion small lead/lag (5m)

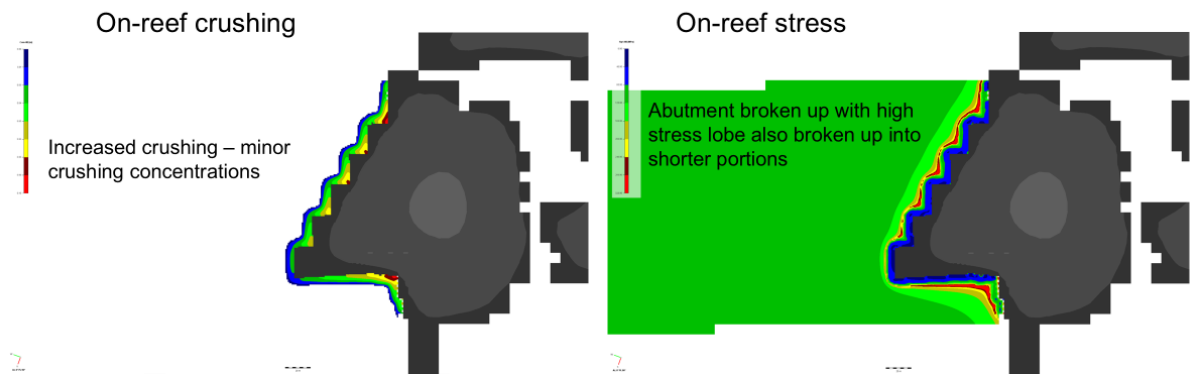


Minor lead/lag fractures

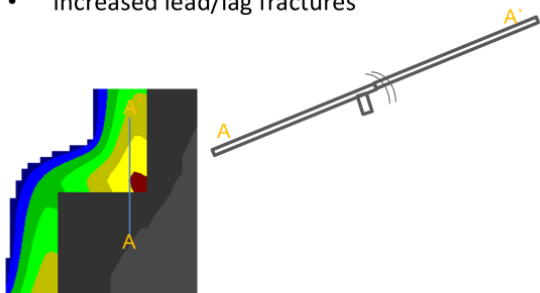


- potential for large event with damage to multiple panels

Lead lag discussion good lead/lag (15m)

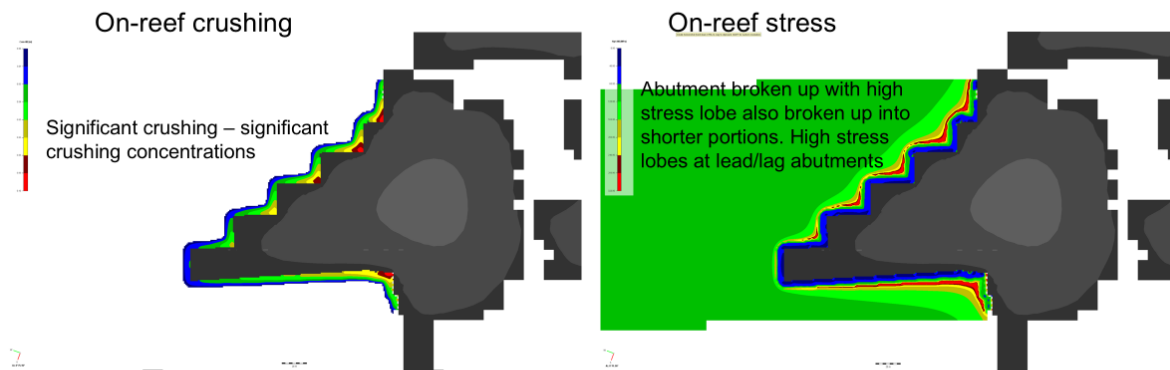


- Increased lead/lag fractures

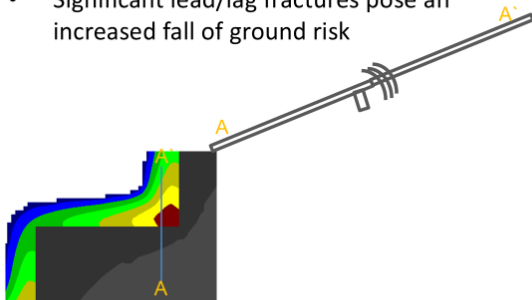


- significantly reduced potential for large event. Potential for multiple smaller events

Lead lag discussion large lead/lag (25 m)

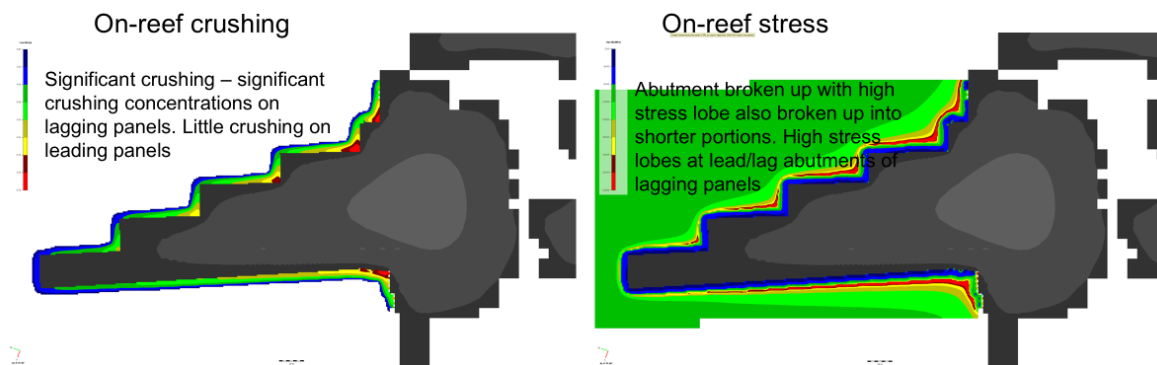


- Significant lead/lag fractures pose an increased fall of ground risk

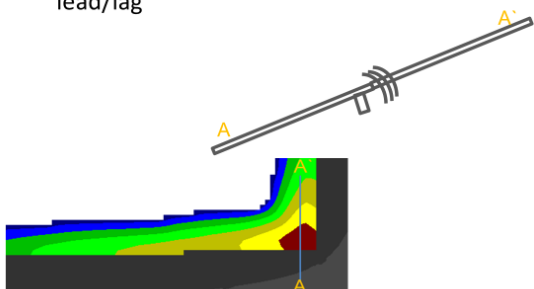


- significantly reduced potential for large face related event. Potential for multiple smaller events.
- Increased potential for lead/lag abutment related events
- increased vulnerability of lead/lag abutment under seismic loading conditions due to high abutment stress

Lead lag discussion very large lead/lag (35 m)



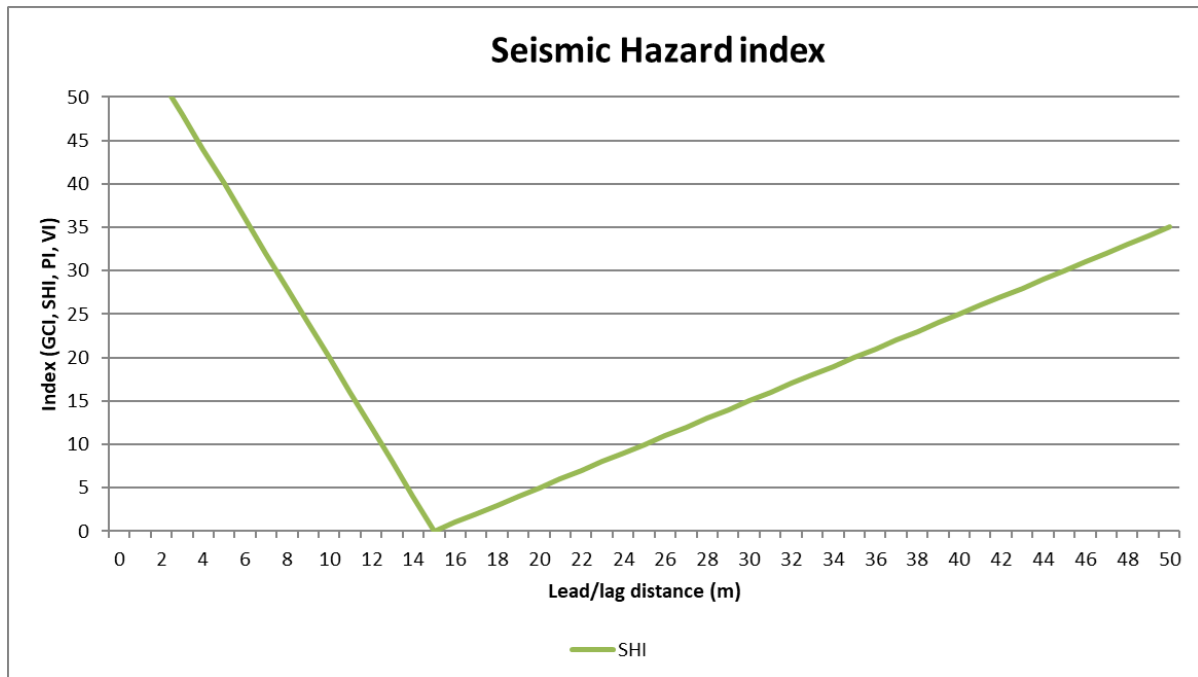
- Significant lead/lag fractures pose an increased fall of ground risk – similar to 25 m lead/lag



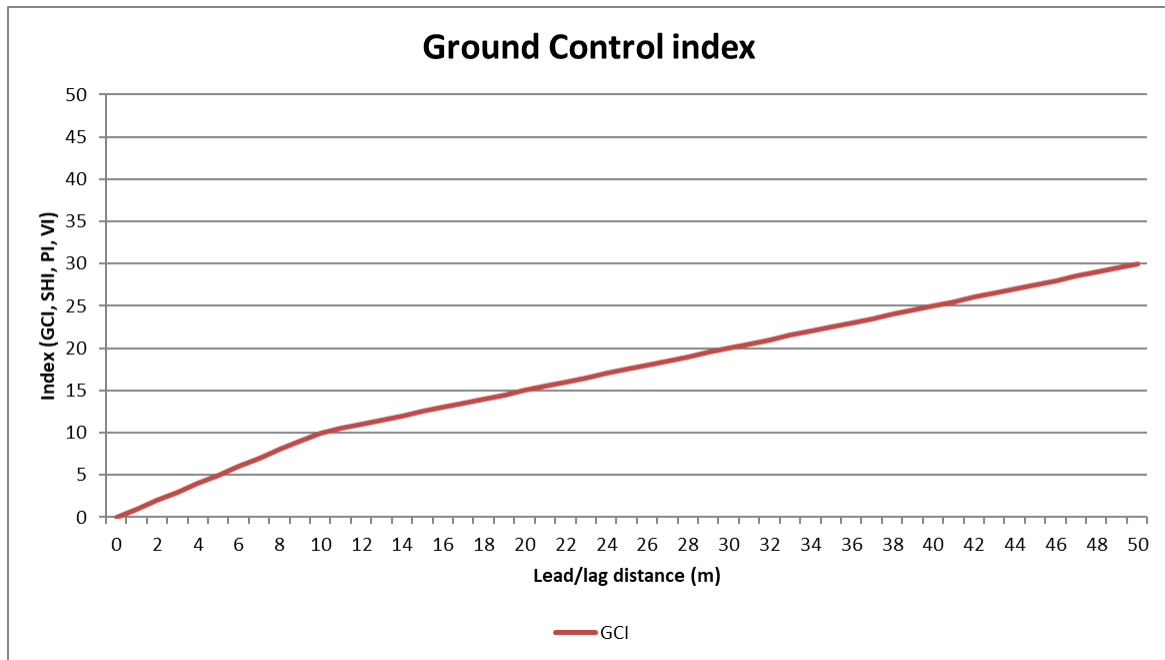
- significantly reduced potential for large face related event. Potential for multiple smaller events.
- Significant potential for lead/lag abutment related events
- increased vulnerability of lead/lag abutment under seismic loading conditions due to high abutment stress

Determining the ideal lead-lag range

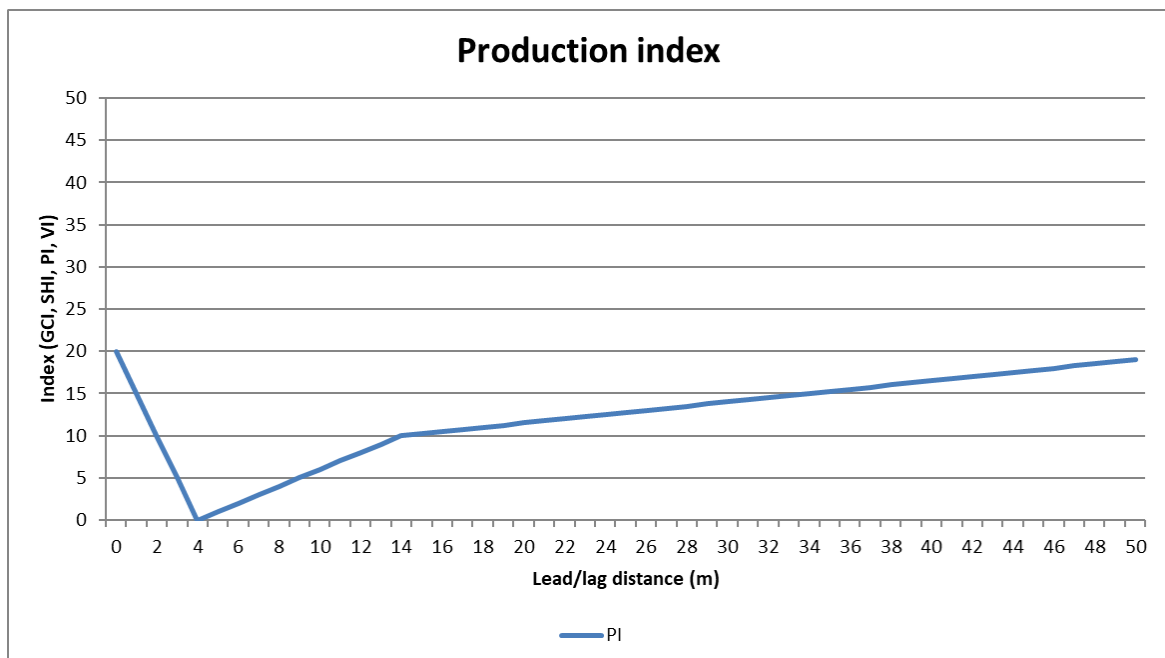
- SHI (seismic hazard index)
 - High values indicate high seismic hazard
 - Subjective interpretation by experienced rock engineers and seismologist
 - With very small lead/lags (<3m) the SHI is extremely high due to the possibility of longwall parallel failure. This improves with increasing lead/lags up to 15 m. With excessive lead-lags the SHI starts increasing again.



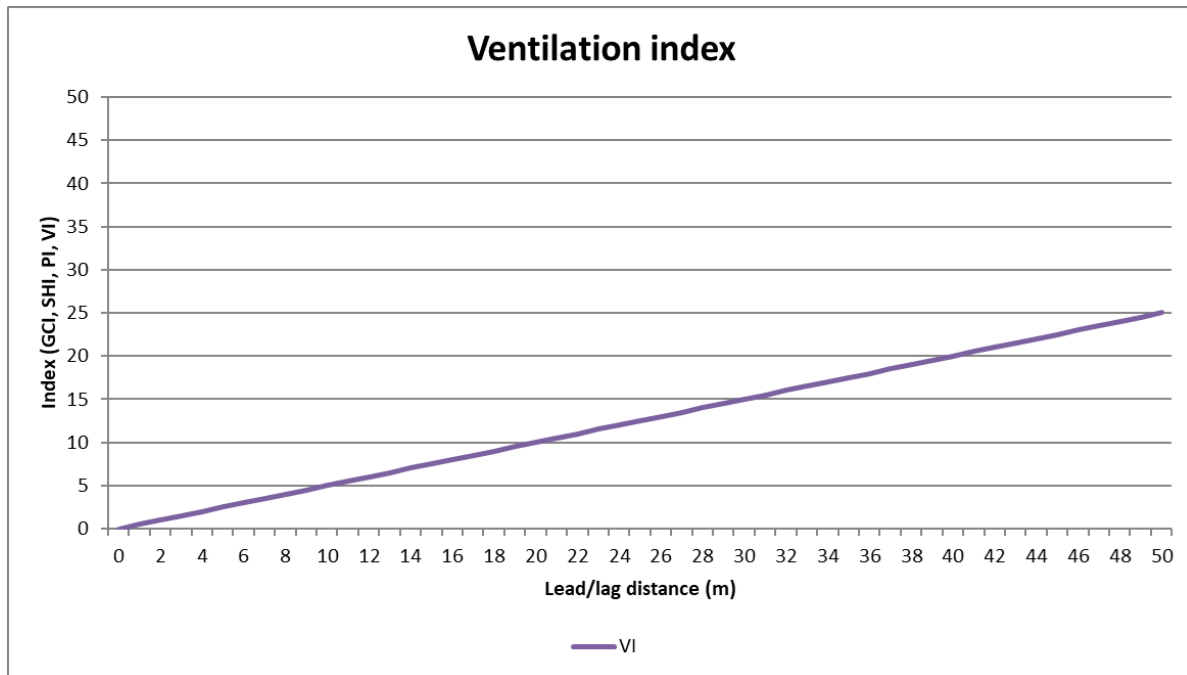
- GCI (ground control index)
 - High values indicate high fall of ground hazard due to poor ground conditions
 - Subjective interpretation by experienced rock engineers and production supervisors (risk assessment team)
 - With very small lead-lags (<3m) the GCI value is low. This increases rapidly with increasing lead-lags up to 10 m. With further increase in lead-lag distance the GCI increases at a low rate as the fractures have been formed



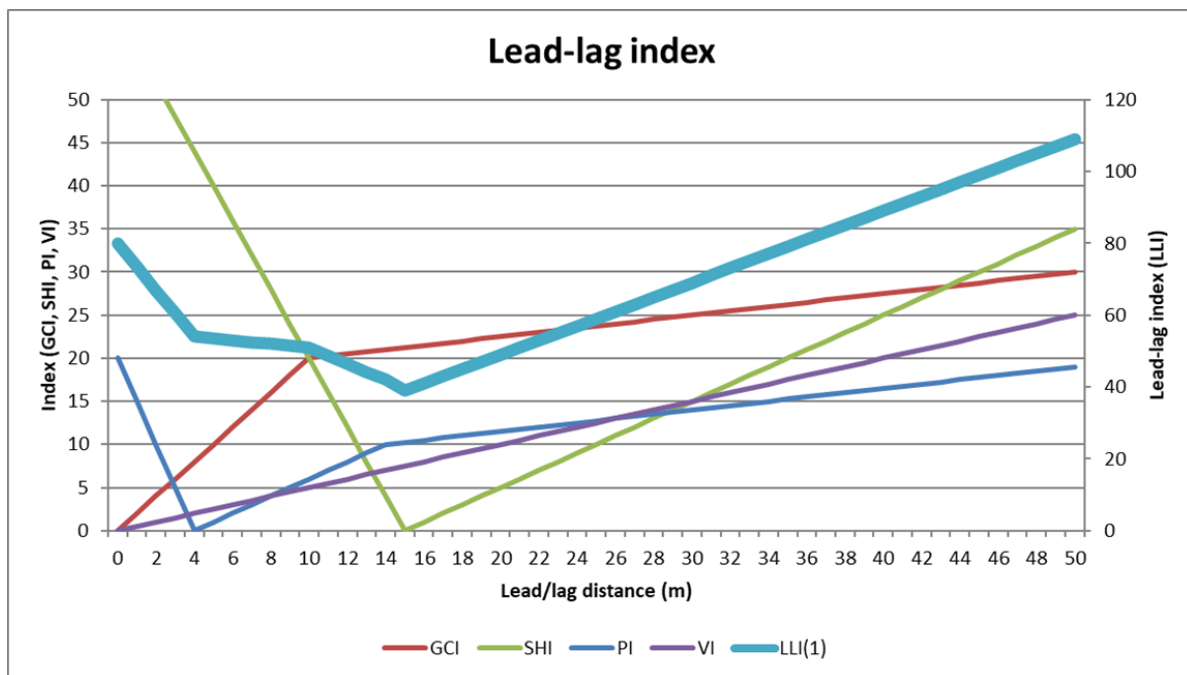
- PI (production index)
 - High values indicate production difficulties, especially cleaning/scraping
 - Subjective interpretation by experienced production supervisors (risk assessment team)
 - With very small lead-lags (<3m) the PI value is high due to no overrun for the gully scraper. This decreases rapidly with increasing lead/lags up to 7 m. With further increase in lead-lag distance the PI increases at a low rate.



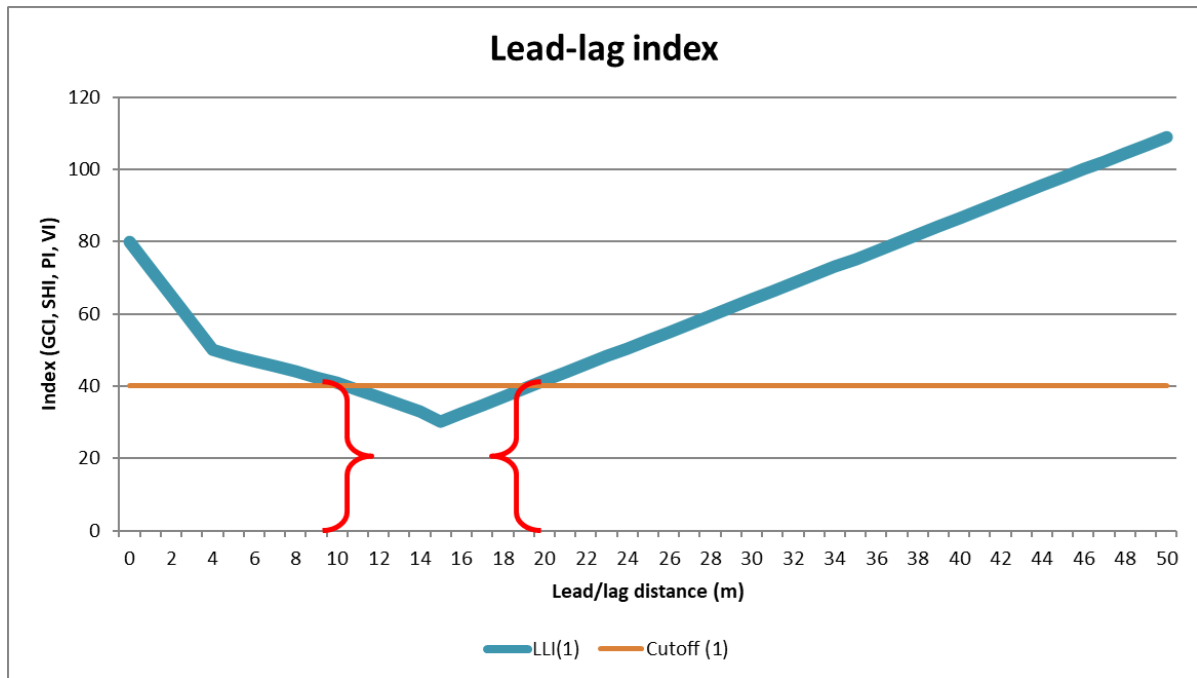
- VI (ventilation index)
 - High values indicate inefficient/insufficient ventilation
 - Subjective interpretation by experienced production supervisors and ventilation officer (risk assessment team)
 - The VI value increases with increasing lead-lags



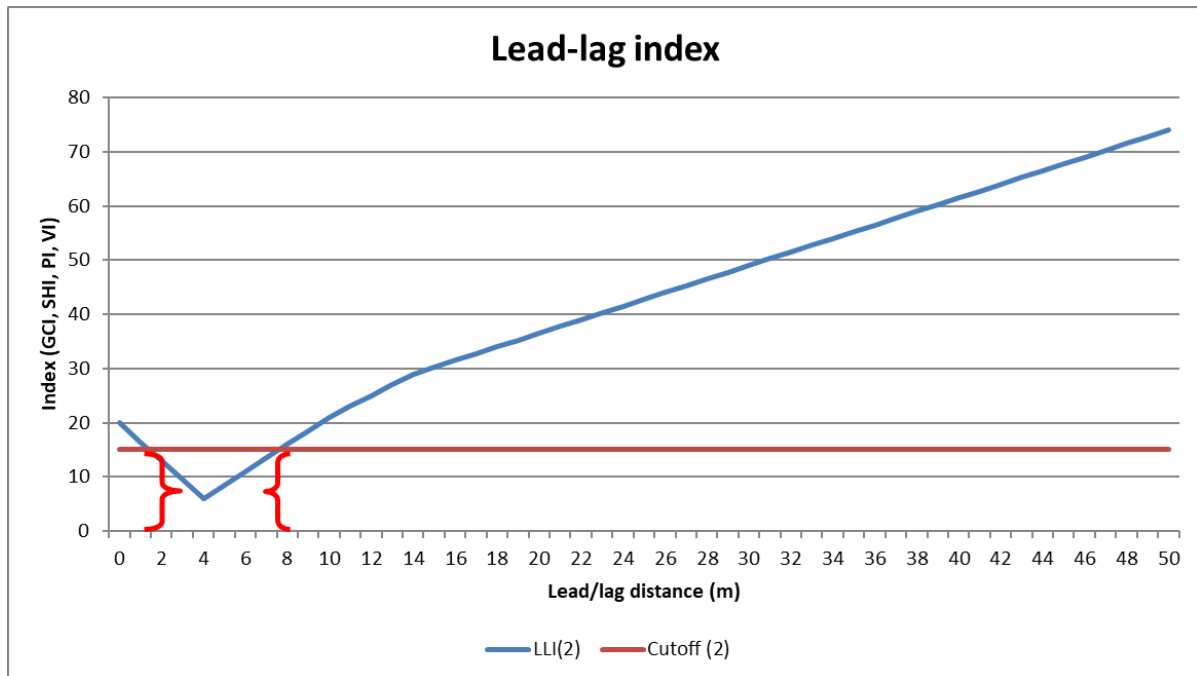
- LLI (lead-lag index)
 - This is the sum of the SHI, GCI, PI and VI



- LLI (lead-lag index for deep level or seismically active mines)
 - High values indicate increased mining hazard due to lead-lags
 - The cut-off or ideal lead-lag is still a subjective value but guided by a logical risk assessment process.
 - The acceptable lead-lag range for seismically active mines is 10 m to 20 m



- LLI (lead-lag index for shallow or low seismic risk mines)
 - High values indicate increased mining hazard due to lead-lags
 - The cut-off or ideal lead-lag is still a subjective value but guided by a logical risk assessment process.
 - The acceptable lead-lag range for mines with low seismic hazard is 2 m to 8 m



Determining the ideal lead-lag range: conclusions

- In the deep seismically active mines (Driefontein excluding portions of D8 and Kloof) the ideal lead-lag is 15 m (allowable range between 10 m and 20 m).
 - Lead-lag abutment related fracturing is expected and must be mitigated with additional support

- In the shallower mines (portions of D8, Beatrix and Burnstone) the ideal lead-lag is 5 m. Lead-lag control is less important.
- When mining through a geological structure, the lead-lag distances are based on maintaining an approach angle of 35° between the overall mining front and the structure orientation (not individual panels). This supersedes the ideal lead-lag distances discussed above.



Lourens Johannes Scheepers

Manager Rock Engineering
SibanyeStillwater

27 years in the mining industry, all in deep level gold mines, in the rock engineering departments of Vaal Reefs, AngloGold Ashanti and SibanyeStillwater. Career focussed on the management of seismic risk and presented papers on the rock engineering aspects of mine seismicity.

Update of the South African mining rock stress measurement database

Z. Nkosi

Mine Health and Safety Council and BKM Engineering, South Africa

INTRODUCTION

The deep-level mines of South Africa face significant challenges related to rock stress. With over a century of mining having taken place, operations now lie at depths ranging from ~1 to 4 km below the surface, within highly stressed rock. In such environments, mining activities pose serious risks to both mineworkers and infrastructure in proximity to mining regions. Mineworkers are particularly vulnerable to falls of ground, rockbursts, mining-induced fracturing, and large damaging seismic events. Consequently, an enhanced understanding of seismogenic processes, coupled with consistent and accurate stress measurements, becomes imperative for the implementation of effective risk mitigation strategies in deep and highly stressed ground conditions.

In response to these challenges, the Mine Health and Safety Council initiated this project aimed at providing a comprehensive and up-to-date repository of rock stress data¹. This project aims to address several key objectives, including reviewing existing projects such as SIMRAC GAP 511 and SIM 160202, updating stress measurement data, developing a user-friendly web-based application/system for stress measurement records, and compiling an operator manual to guide users.

Procedure

The methodology applied in this project involved several key steps to achieve the objectives of updating and enhancing the repository of rock stress data. These steps included review of previous projects, data collection and compilation, development of a web-based application/system, incorporating an operator manual, workshop and feedback, and data validation and integrity checks.

Summary of results

The review of SIMRAC GAP 511 and SIM 160202 highlighted the importance of regularly updating stress data and integrating advancements in stress measurement techniques. These techniques, such as Diametrical Core Deformation Analysis and modified compact conical-ended borehole overcoring, have shown potential in measuring in-situ stress at depths exceeding 3 km. The review also identified and incorporated 447 historical stress data records into the new database, while ensuring data integrity by excluding records with incomplete or invalid information. Additionally, 11 new stress measurement records were obtained from various South African mines, further enriching the database.

A key outcome of the project was the successful development of a user-friendly stress measurement data application (Figure 1). This web-based system allows users to enter, filter, and download stress data, with functionalities designed to cater for both general users and administrators. General users can view and export data, while administrators can manage user profiles, edit records, and ensure data quality.

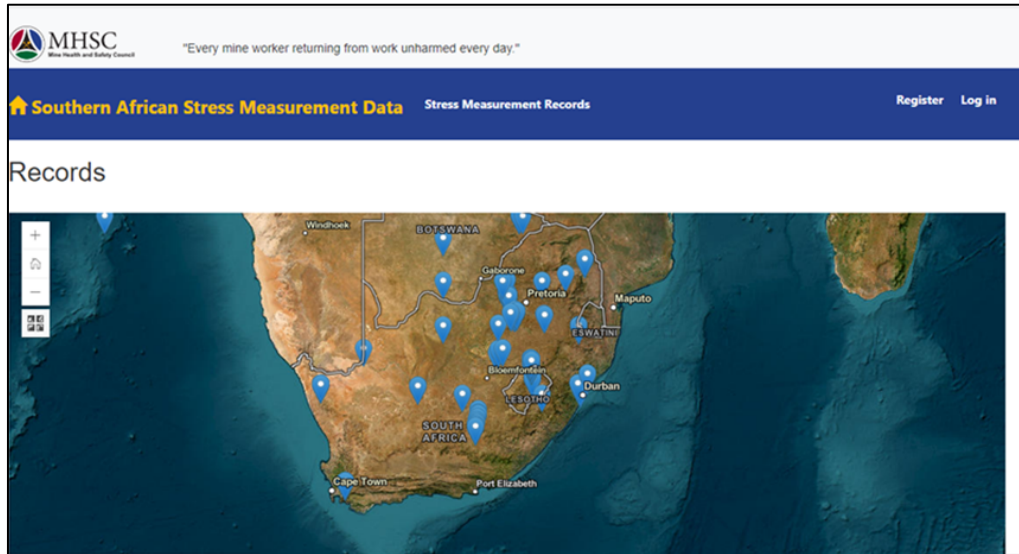


Figure 1. Homepage for the stress measurement data application.

The application also features advanced data filtering options and interactive base map displays, enhancing its utility for rock engineers, mining engineers, and other stakeholders in the mining industry.

The operator manual developed as part of the project serves as a comprehensive guide for navigating the new system, detailing procedures for logging in, managing user profiles, and utilising the various functionalities of the application. The manual ensures that users can effectively interact with the database, facilitating better access to and management of stress measurement data.

The updated South African Mining Rock Stress Measurements database and the associated web-based applications represent significant advancements in the management and utilisation of stress data. By streamlining data entry, sourcing, and filtering processes, the project enhances the decision-making capabilities of stakeholders in the mining industry. The inclusion of new and historical stress data provides valuable insights for managing stress-related challenges in deep-level mines, contributing to improved safety and operational efficiency.

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Zamaswazi Nkosi

Research Delivery Specialist (Mine Safety)
Mine Health and Safety Council

Zamaswazi Nkosi, is an accomplished geoscientist deeply committed to addressing geological and geotechnical challenges within the mining sector to enhance mining safety. She holds a Master's degree (MSc - Cum Laude) in Geology, a BSc (Hons) in Geology, and a BSc in Geology. Currently, she is pursuing a PhD in Geology, specialising in Geology, Geophysics, and Rock Engineering. With hands-on experience in participating in international and South African mining and geotechnical projects, Zamaswazi has demonstrated her expertise across various mining-related fields. Her professional experience extends to advanced mining research, where she has conducted geophysical surveys, seismic imaging, and subsurface characterisation. Zamaswazi has contributed to various research projects, publishing her findings in peer-reviewed journals, and books and presenting at industry conferences and workshops. Zama plays a vital role in advancing mining research initiatives, ensuring compliance with regulatory standards, and fostering collaboration among project teams.

Study on good ledging practices and the development of virtual video training material based on good ledging practices

Z. Nkosi

Mine Health and Safety Council and BKM Engineering South Africa

INTRODUCTION

Ledging can be defined as the process of establishing the initial footwall ledge for a stope by taking the first cut from the original raise. This process ensures the formation of a suitably supported, robust, and competent centre gully for the life of the raise line being mined. However, the ledging process is associated with several inherent risks and hazards due to the span of unsupported hanging wall exposed before the installation of permanent support. Ledging is an essential phase of the mining process as it often determines the stability and longevity of the raise or centre gully.

This project was initiated by the Mine Health and Safety Council to address concerns about the current shortfalls in ledging-specific training content in the South African Mining Industry (SAMI) and to improve the safety and productivity of the ledging process. The project aimed to review ledging best practices implemented in the industry and develop a guideline document in consultation with industry experts and practitioners.

Procedure

The methods followed to achieve the objectives of the project are indicated in Figure 1.

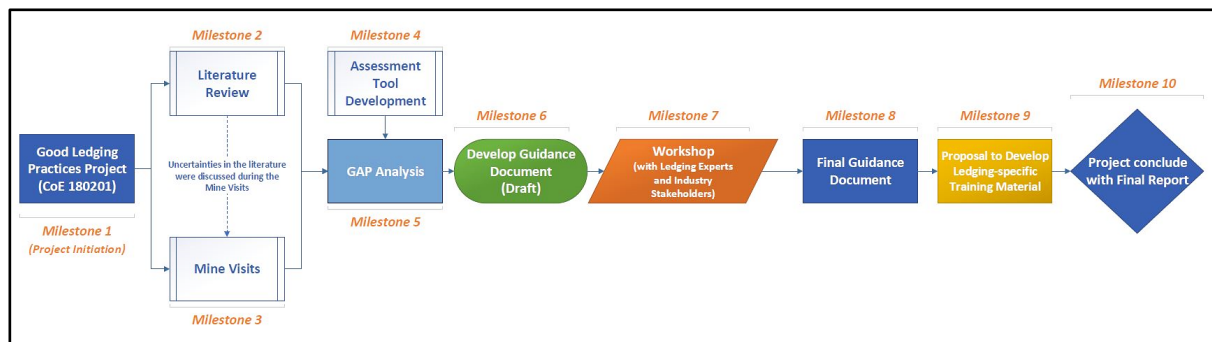


Figure 1. Procedure followed for project execution.

Summary of results

The information gathered from the literature review and mine site visits was utilised to develop an assessment tool aimed at performing a gap analysis to identify ledging topics lacking adequate information or technical content. The assessment tool proved effective in this analysis and holds potential for use by mining operations to conduct 'self-audits' of their ledging and related practices. Through the evaluation of identified gaps, the tool was instrumental in pinpointing good ledging practices.

Additionally, a good practice ledging guidance document was created. This document is not intended to serve as a prescriptive, step-by-step manual for ledging in the SAMI, but rather to offer key considerations for various phases within the ledging operation. The guidance document is envisioned as a foundation for the future development of ledging-specific training material in the SAMI.

Conclusion

The conclusion of the project culminated in the development of a comprehensive ledging guidance document, derived from industry best practices and expert knowledge. This document serves as a valuable resource for mining operations in the SAMI, offering guidelines tailored to varying geological and geotechnical conditions. It is emphasised that while the guidance document is not intended to be a prescriptive manual, it provides essential considerations for each phase of the ledging operation.

Key components of the guidance document include:

- A ledging-selection flow diagram (Figure 2) to aid in selecting the most suitable ledging method for different mining environments.
-

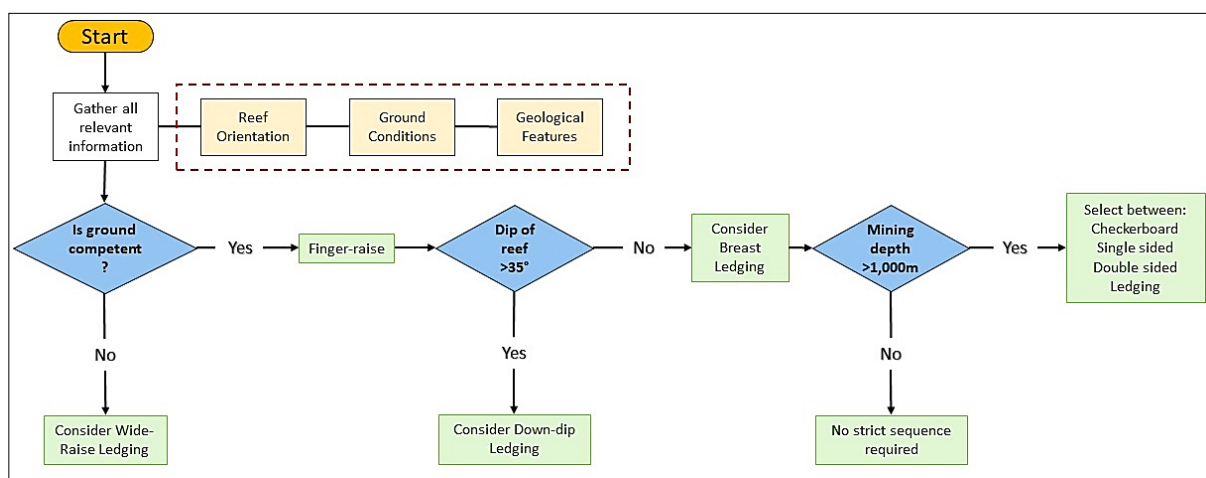


Figure 2. Ledging method selection flow diagram.

- Emphasis on the importance of an ore reserve management plan and a development service strategy plan as foundational elements for ledging and future stoping activities.
- Pre-ledging (Figure 3) and post-ledging flow (Figure 4) diagrams, accompanied by key considerations and guidelines for down- and up-dip ledging, breast and wide-raise ledging, as well as over-stoping.

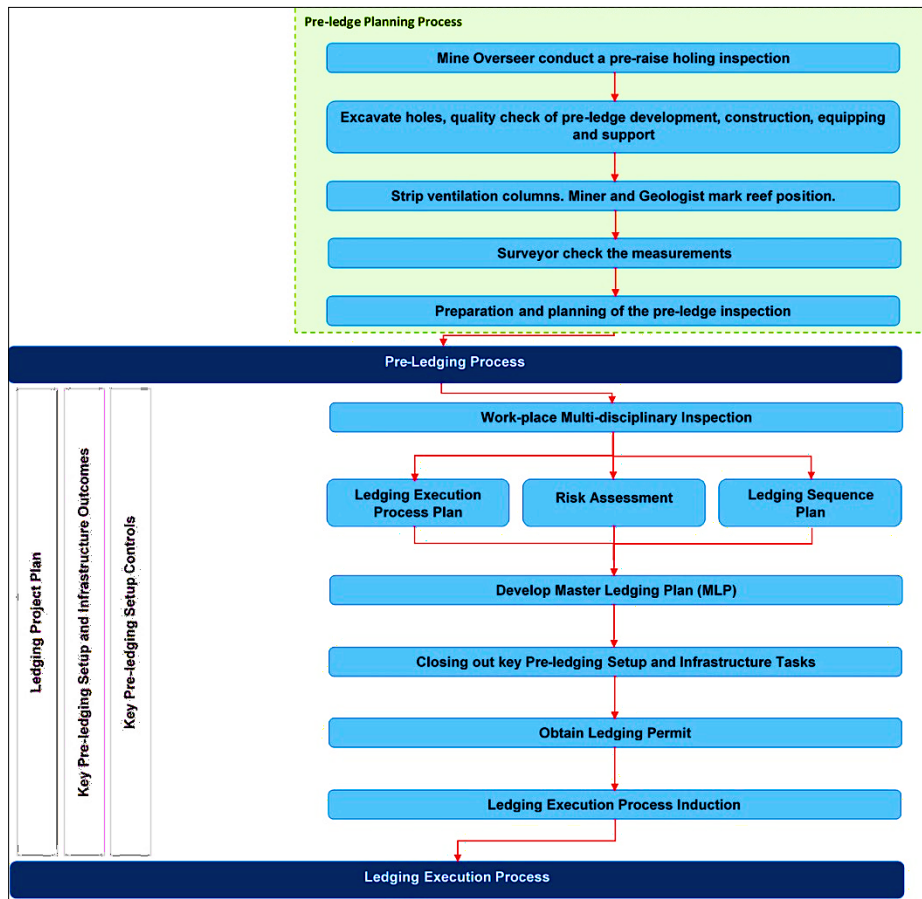


Figure 3. Pre-ledge process flow diagram.

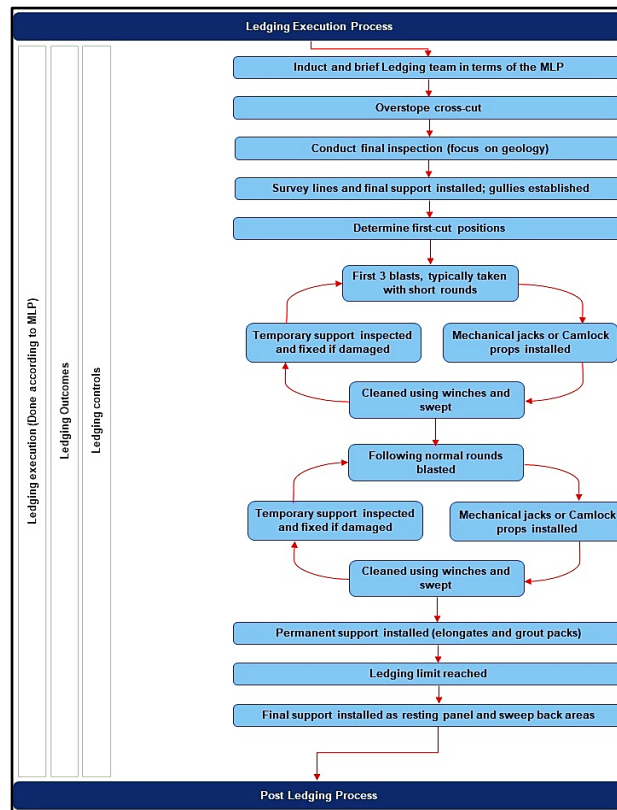


Figure 4. Illustration of the ledging process up to the post ledging process.

- Guidelines for post-ledging operations, including enabling and supporting factors for successful ledging operations.



Zamaswazi Nkosi

Research Delivery Specialist (Mine Safety)
Mine Health and Safety Council

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From suspicion to submission – An occupational lung disease handbook

V.G. Govender

Masakhane Strategic Health Consulting (Pty) Ltd, South Africa

INTRODUCTION

From the suspicion of an occupational lung disease (OLD) to the submission for compensation, occupational medicine practitioners (OMPs) in the South African Mining Industry (SAMI) practice under the Occupational Diseases in Mines and Works Act No. 78 of 1973 (ODMWA)¹ and its Regulations. These OMPs collectively hold decades of institutional knowledge in the practical implementation of the ODMWA. While the science has advanced considerably, laws and guidelines remain outdated and fragmented. Without updated guidelines, OMPs are challenged to provide the optimal management of their patients afflicted with OLDs.

Methods

The objective of the Handbook was clear: by assisting occupational health doctors within South Africa and beyond its borders with a set of guidelines that can be applied consistently, from suspicion to submission of OLDs in mineworkers (current, former and deceased) who have worked in the SAMI, we can ensure that OLDs are diagnosed early, mineworkers are optimally managed during employment and in the post-employment phase, and exposures are effectively controlled.

From conceptualisation to the publication of the Handbook, prevention of OLDs was the main focus, with guidance on how to apply science, art and heart with excellence. The methodology involved a robust desktop literature research, professional networking, including attendances at international conferences and visits to state-of-the-art occupational health facilities for current and former mineworkers in the USA. Key learnings were taken from global counterparts, in understanding the patterns of disease and preventative interventions, e.g. the recent resurgence of Black Lung disease in the USA^{3,4} and progressive policy changes in the engineered stone industry in Western Australia⁵. Extensive research and a collaborative process with subject matter experts ensued, to redefine how we can apply ourselves within the context of outdated legislation, emerging science and advanced technologies, as occupational health professionals.

After a four-year journey to develop the blueprint, in August 2024, the Handbook, 'From Suspicion to Submission – Occupational Lung Diseases in the South African Mining Industry'², was launched at the School of Public Health, Wits University.

Results

The Handbook is a compendium of eight chapters with a useful glossary of terms and definitions, real case studies and informative sections on legislation, principles, key concepts, occupational health policy development, assessing pulmonary impairment, reading chest X-rays according to the international radiographic classification and postmortem examinations. Quick reference guides on the pneumoconioses, tuberculosis, chronic obstructive airways disease, occupational asthma and lung cancer, are provided to guide even the most novice mine doctor. Thought-provoking best practices in occupational health such as a respiratory medical surveillance programme that goes beyond regulatory requirements, is documented, detailing the medical tests and interventions for individualised case management, as well as company-wide policies aimed at promoting wellness in mineworkers. The Handbook closes with a chapter in question and answer format about the benefit medical examinations under the ODMWA.

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The Southern African Institute of Mining and Metallurgy*

DISCUSSION

On 18 October 2024 in Johannesburg, the State, employers and employees committed to the revised milestones to eliminate the OLDs by 2034. This pledge calls for an acceleration of collaborative, multidisciplinary, and multilayered responses, placing greater pressure on occupational health professionals.

As the Handbook is scientific and technical, it covers more than just the ODMWA compensatable diseases, whilst introducing global best practices. As such, it offers practitioners theoretical and practical nuggets of wisdom to achieve these aspirational goals.

The Handbook is an invaluable desktop tool aimed at OMPs, but should be used for the ongoing training and education of all occupational health professionals, and be a companion to occupational health service providers, mining executives, human resources, exposure scientists, engineers, legal professionals, as well as mineworkers and their families.

CONCLUSION

The Handbook serves as a set of guidelines that is rooted in the author's and experts' collective professional expertise in local, national, regional and global occupational health settings, and does not replace any existing laws or codes of practice.

The journey from conceptualisation to publication of a Handbook, is a labour of love, that should inspire occupational health professionals to conduct research and share their knowledge widely.

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Vanessa Govender

Director, Occupational Medicine Specialist
Masakhane Strategic Health Consulting (Pty) Ltd

Dr Vanessa Govender is a registered Specialist in Occupational Medicine and Director of Masakhane Strategic Consulting Pty Ltd. She has 30 years global experience in health leadership, strategy and policy development for the mining and related sectors. She attained her Medical Degree, Diploma in Occupational Health and Masters in Public Health (Policy and Management), Travel Medicine and International Executive Development qualifications from the University of Witwatersrand, South Africa, and Aviation Medicine from the University of Pretoria. She serves as an honorary lecturer at the Wits School of Public Health and is an Associate of the Colleges of Public Health Medicine in South Africa, and serves as alternate member on the Medical Advisory panel of the Tshiamiso Trust.

Empowering miners: The key to safer underground operations

N. Weideman¹, D. Piketh¹, M. Armstrong¹, and M. Pienaar²

¹STRATAFY, South Africa

²Mandela Mining Precinct, South Africa

Narrow reef mines in South Africa present significant challenges due to the effects of drilling and blasting on complex geological structures at extreme depths. These environments carry higher risks, particularly concerning the stability of the hanging wall and side walls, which can be compromised by human activities and natural rock mass instability. Recognising these dangers, the Stratafy Seeker, a sophisticated tool, enhances miner safety through providing additional safety steps in the operations, without hindering current productivity. This device uses photogrammetry to scan the region of interest and delivers near real-time 3D representations to a user's handheld device. Although technologically advanced, the Stratafy Seeker's user-friendly design and comprehensive monitoring capabilities empowers miners to operate more safely and effectively. Stratafy's commitment to continuous innovation and field testing ensures that the Seeker will remain a vital tool for enhancing safety and efficiency in underground mining operations, ultimately safeguarding the well-being of workers and improving overall operational resilience.

Keywords: Narrow reef mines, Stratafy Seeker, photogrammetry, enhancing miner safety, real-time 3D representations

INTRODUCTION

Narrow reef mines in South Africa face considerable challenges due to their unique geological conditions and the inherent risks associated with deep mining operations (Pickering, 2007). The effects of drilling and blasting can lead to significant instability in both the hanging wall and side walls (Katuwal and Adhikari, 2023). The complexity of geological structures at these depths means that even minor disturbances can trigger rock falls or collapses, posing safety risks to workers and impacting mine operations (Australian Centre for Geomechanics, 2018; Netshilaphala and Zvarivadza, 2022). High-stress conditions found at depth can exacerbate these issues, leading to unpredictable rock behaviour. To mitigate these risks, mining companies often conduct detailed geological mapping and assessments as well as rock mass characterisation to understand stability and identify potential failure zones. Implementing robust ground support solutions, such as rock bolts and shotcrete, helps reinforce weak areas.

Recognising these dangers, Stratafy, an innovative technological solution, has focused on enhancing the miner's safety through targeting the early identification and visualisation of shallow dipping fractures and joints (or discontinuity) sets. Its primary objective is to develop a procedure that minimises human exposure to high-risk areas while maintaining effective monitoring and data collection. To achieve this goal, Stratafy has introduced the Stratafy Seeker.

The Stratafy Seeker is a sophisticated device that can detect and alert users of potential hazardous structures or rock features in the underground environment. It integrates some existing proven technologies with its own innovation to provide additional safety steps in the operations, without hindering current productivity. This device scans the region of interest and delivers near real-time 3D representations to a user's handheld device. These representations enable automated software processes to provide immediate feedback on potential risks and hazards, enhancing safety protocols.

The Stratafy Seeker is a sophisticated device that can detect and alert users of potential hazardous structures or rock features in the underground environment. It integrates some existing proven technologies with its own innovation to provide additional safety steps in the operations, without hindering current productivity. This device scans the region of interest and delivers near real-time 3D representations to a user's handheld device. These representations enable automated software processes to provide immediate feedback on potential risks and hazards, enhancing safety protocols.

Methodology

It is well known that achieving safe production requires a combination of the correct equipment, personnel with necessary training and operating guidelines (Pickering, 2007). Although technologically advanced, the Stratafy Seeker can be easily adopted by any individual, ensuring user safety independently from technical staff intervention. The Stratafy Seeker uses photogrammetry, theoretical principles, and automatic feature extraction. The Seeker focuses on scanning every active working area in underground mines, including where drilling, blasting, and mechanised mining occur. The goal is for the seeker to conduct scans across various mining operations, encompassing conventional mining methods, board-and-pillar techniques, and more. The vision is to integrate these monitoring tools into the Early Entry Examination process, allowing real-time identification of problem areas. The instant, real-time data guides operators on whether it is safe to proceed, and if hazardous conditions are detected, employees will be alerted, and entry into the affected area will be prohibited, followed by continuous monitoring and updated risk plans to restore stability.

Equipment selection and testing design

The Stratafy Seeker comprises a software and hardware component (Figure 1). The hardware component, referred to as the Telescopic Scanning System, includes a telescopic scanner head (synoptic camera set-up) and hand-held device (touch screen). The software component includes an Open Source cloud processing interface in the Stratafy eco-system. During the Early Entry Examination process, a user will use the telescopic scanner head to physically scan 1-3 m of the newly blasted section, utilising the extended Telescopic Pole to remain underneath the supported area (Figure 2), which then in near real-time produces a 3D representation of the scanned zone which is displayed on the user's handheld touch screen. This will initiate a series of automatic software processes that eventually provide the user with feedback regarding relative risks Indicators (if any) to aid in the Safe Declaration process.

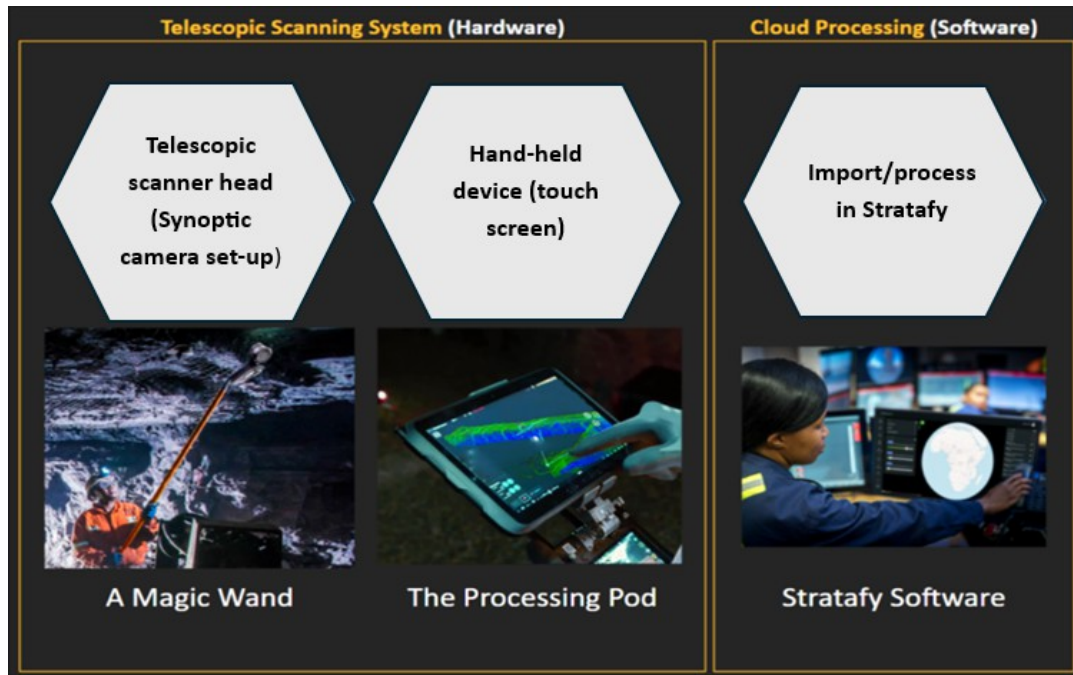


Figure 1. Overview of the hardware and software components in the Stratafy Seeker.



Figure 2. The scanning process.

Data

Once the scanning of an underground chrome mine (Mine A) was completed, a sequence of software procedures (from the cloud processing software in the Stratafy eco-system) were initiated, and the outcomes are shown in Figure 3-5. The software generated a point cloud that was scaled and geo-referenced into a Spatial Data Workspace (Figure 3a & Figure 3b). A 3D model of the scanned area was then displayed (including the small details). Based on the 3D model the support, location and spacing of supports were digitally located and measured. The model also highlighted significant structures such as low hanging features, discontinuity sets (Figure 4) and plane extrapolation were used to locate wedges and intersecting planes (Figure 5).

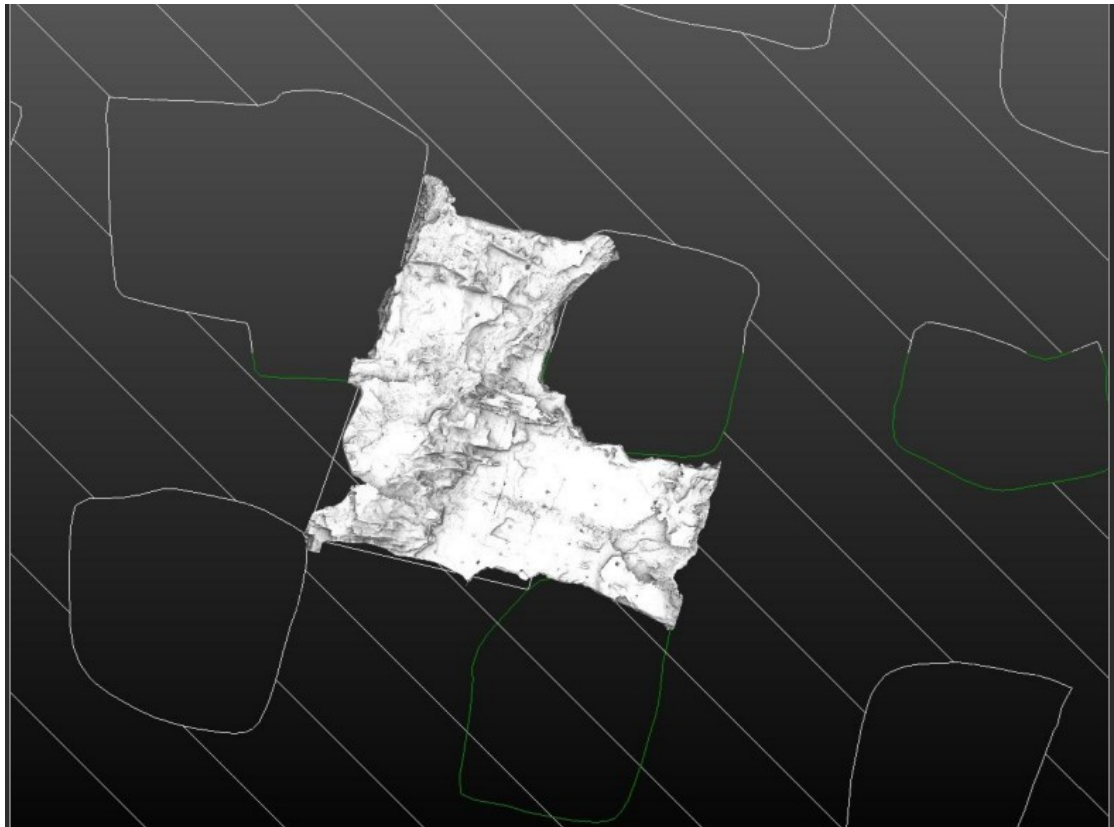


Figure 3a. Scaled and geo-referenced point cloud.

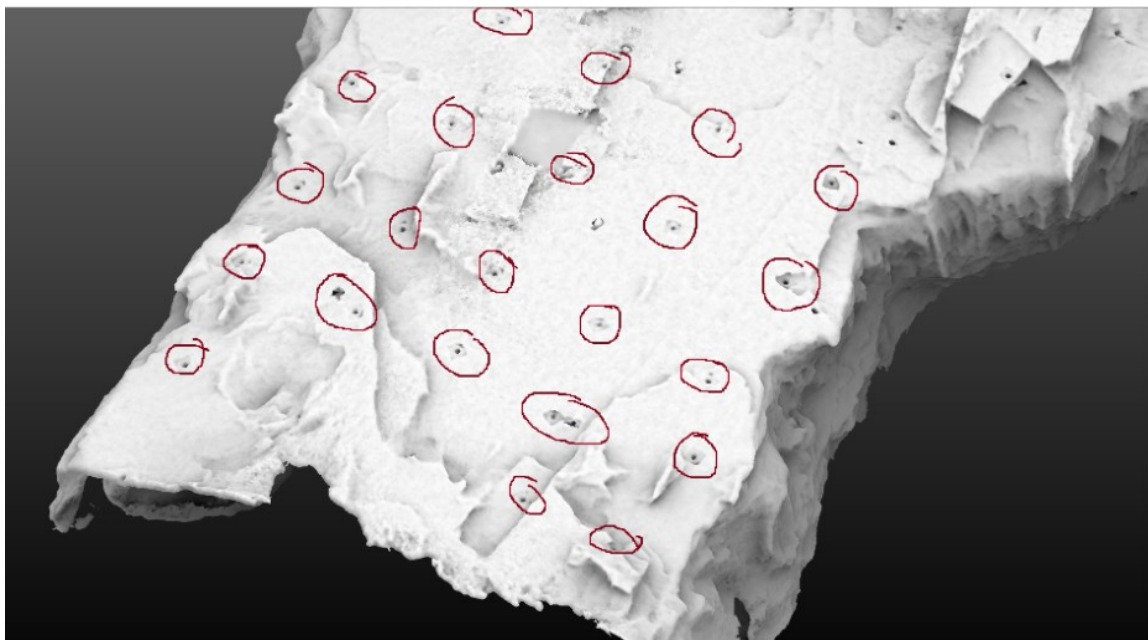


Figure 3b. Scaled and geo-referenced point cloud.

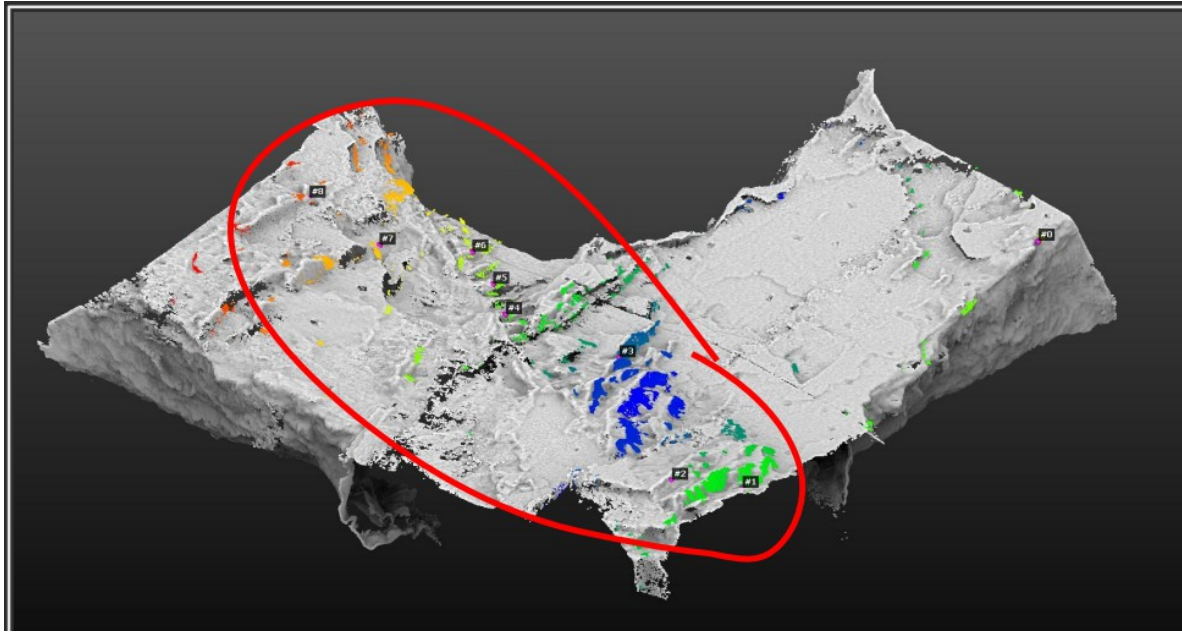


Figure 4. 3D model generated from the scans showing important structures such as discontinuity sets, low hanging features.

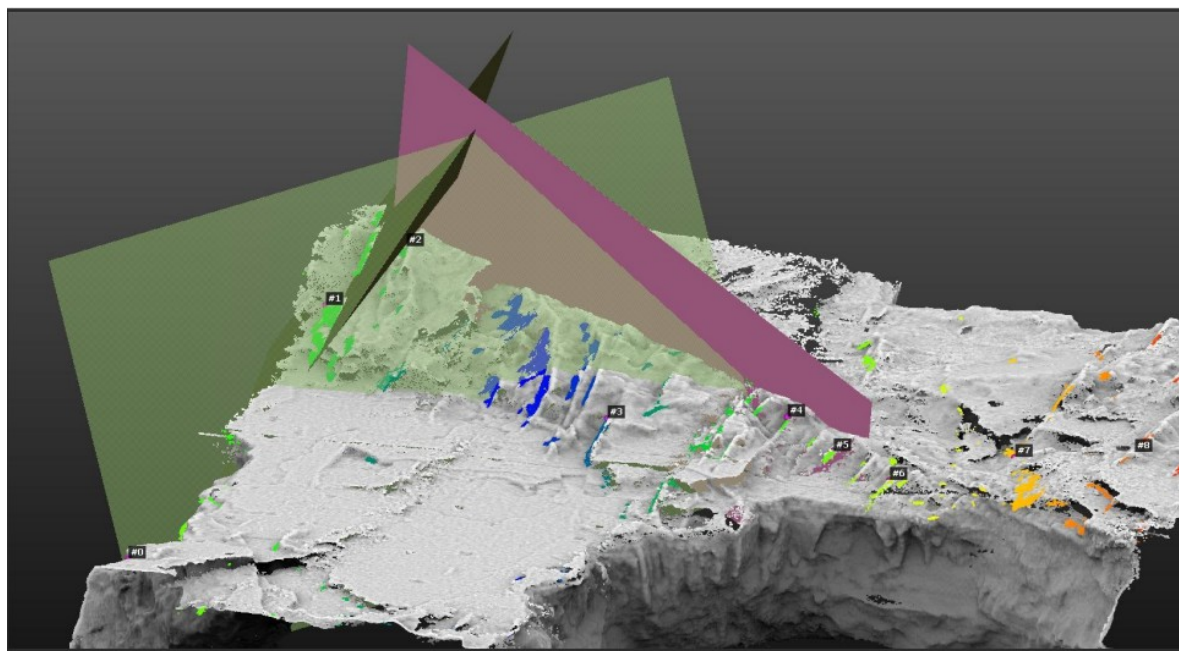


Figure 5. Extrapolated planes to help identify wedges and intersecting planes.

Research findings

The South African mining industry has faced challenges in implementing and applying new technologies, and its attempts have not always succeeded (Pickering, 2007). However, with Stratafy, this has not been the case. Initial proof-of-concept trials have been conducted at selected mines with diverse conditions and mining methods. These trials have demonstrated the capabilities of Stratafy's total solution to digitally collect data from mined openings, detect missing support, assess irregular geometry, and evaluate blasted rock fragmentation. The Stratafy Seeker aims to deliver fundamental outputs, which include detecting installed support, measuring excavation geometry, mapping and

highlighting geological features, monitoring deformation, and measuring rock fragmentation post-blast. The principal goal of the project is to create a practical and cost-effective tool for enhancing safety by identifying and visualising geological and rock hazards. This involves combining the Stratafy Seeker Scanner (Syntopic Camera Array) plus the Hand Held Touch Screen in combination with Stratafy's Open Source processing platform for GIS data, to deliver near-real-time 3D models (Figure 6) to both the handheld device operator as well as the subsequent online platform users. The current practice for detecting loose or hazardous rocks places miners in dangerous zones. Therefore, the invention of the 'Digital Pinch-Bar' (Seeker Scanner) aims to prevent miners' direct placement in high-risk areas. As a result, the digital-pinch bar (Seeker Scanner) extends further into these areas while the user remains under the supported zones to produce a digital model of the region of interest, providing considerably more in-depth detail about the rock-mass and geological structures. The pod will use an in-house software and custom operating system to complete On-Device post-processing of 3D data and display it to the underground user and subsequently distribute it throughout the organisation by means of further cloud processing for ingestion into the surface IT system at large.

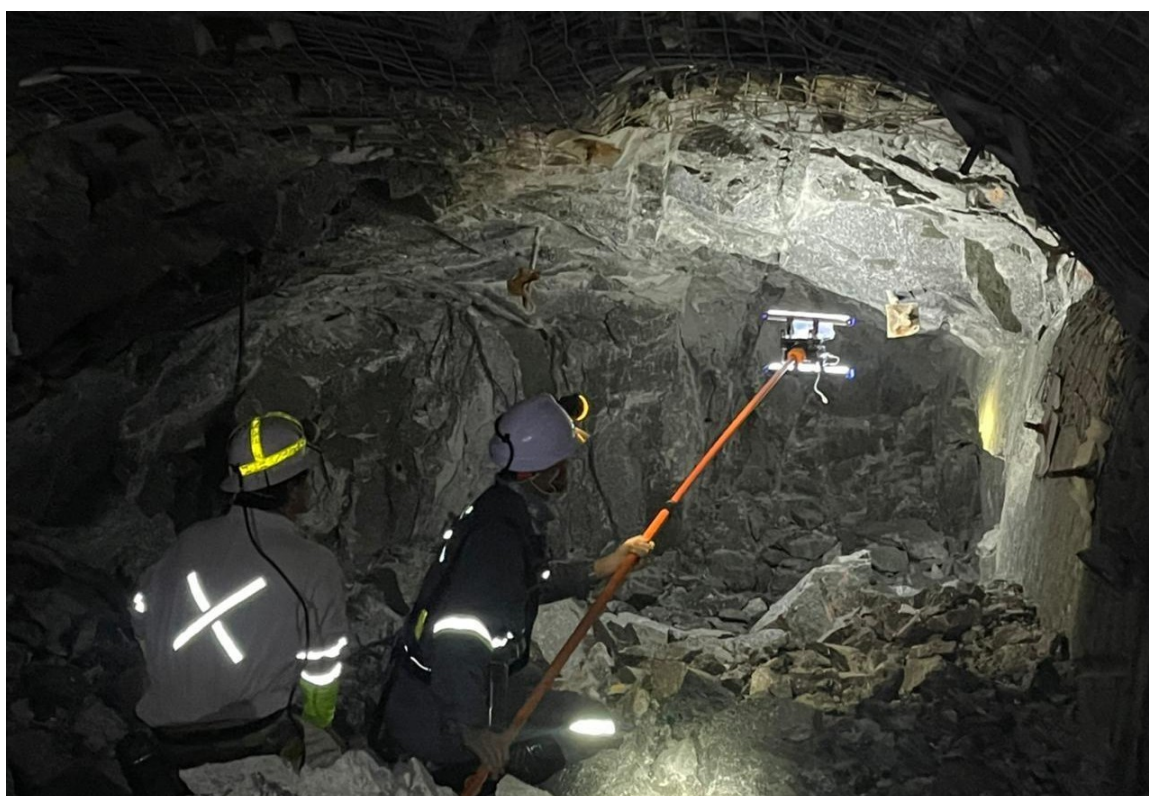


Figure 6. An early version of the Seeker Scanner (digital pinch-bar) – note operator remain under supported area.

CONCLUSION

The environment in which mining is conducted cannot be changed; however the Stratafy Seeker represents a significant advancement in mining safety, specifically tailored to address the unique challenges faced by narrow reef mines in South Africa. By integrating innovative technologies such as photogrammetry, time-of-flight sensors and near-real-time 3D visualisations, the device enhances the early identification and assessment of geological hazards, thereby minimising human exposure to high-risk areas. The successful implementation of this technology not only improves operational safety but also facilitates efficient decision-making in dynamic underground environments.

Through its user-friendly design and comprehensive monitoring capabilities, the Stratafy Seeker empowers miners to operate more safely and effectively. As the mining industry continues to evolve, the adoption of such innovative solutions will be crucial in fostering a safer workplace while maintaining productivity. Stratafy's commitment to continuous innovation and field testing ensures that the Seeker will remain a vital tool for enhancing safety and efficiency in underground mining operations, ultimately safeguarding the well-being of workers and improving overall operational resilience.

ACKNOWLEDGEMENTS

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Neil Weideman

Project Director
Stratafy Ltd.

Neil Weideman is an accomplished project director with over 28 years of experience in the mining industry. He is dedicated to enhancing operational practices, particularly in annual report preparation and regulatory compliance. His consulting work has guided organizations in navigating complex industry standards. In addition to his consulting expertise, Neil has specialized in photogrammetry processing for 8 years, contributing to volumetric calculations and GIS technician projects that drive operational efficiency. His role in GIS platform development spans 4 years, during which he has been instrumental on the steering committee, shaping strategic technology initiatives for the mining sector. With a strong understanding of the underground environment and extensive experience in risk reporting, Neil is adept at overseeing projects that prioritize safety and operational excellence. His diverse skill set and commitment to innovation make him a valuable asset in any mining initiative.

Striving for zero harm in the development end

E. Adlard

Salzgitter Mzansi (Pty) Ltd, South Africa

Deep-level hard rock mining is inherently hazardous, and whilst fatality rates have decreased over the past 20 years, a single fatality is one too many, and too many reportable accidents annually result in personal and family hardship and significant lost production. Outside of stopes, the locations for the highest number of accidents are haulages, crosscuts, and in the development end. Recognising this, Salzgitter Mzansi implemented a Six-Step zero harm procedure when redesigning its pneumatic throw loaders, resulting in the operator being able to safely and wirelessly remote control the units under fully supported hanging. Concurrently, the company converted its flagship HL380U loader to a more powerful all-electric machine, resulting not just in major power savings and performance improvement, but with the added benefits of reducing noise, eliminating pollution, improving workspace illumination, and facilitating the acquisition and pre-processing of environmental and performance data.

INTRODUCTION

Despite a seven-fold reduction in fatalities over the past 20 years (Statista, Mining industry fatalities in South Africa from 2000 to 2023), there is still an unacceptably high level of harm in the South African mining industry (Figure 1), with over 80% of serious accidents historically occurring in deep-level hard-rock gold and platinum mines (Mine Health and Safety Inspectorate Annual Report, 2022-2023). These accidents have a wide reach, since on average eight persons are economically dependent upon each mineworker (Curtis M, 2009), and reportable accidents are too often associated with long-lasting or permanent disabilities, affecting 0.6% of the workforce in 2022 (Mine Health and Safety Inspectorate Annual Report, 2022-2023; Statista (2024)).

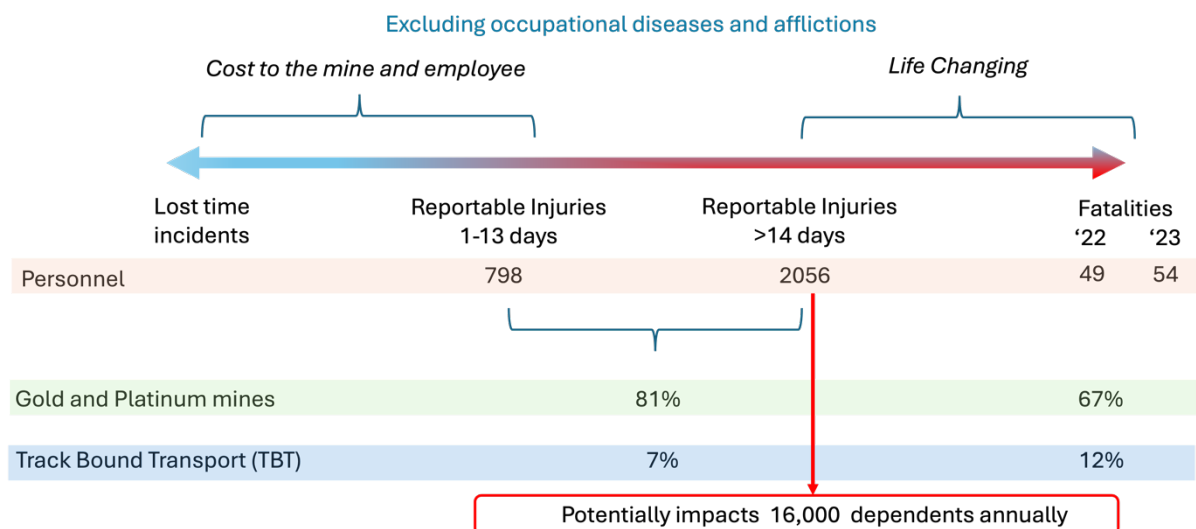


Figure 1. South African mining industry accident statistics in 2022 (Mine Health and Safety Inspectorate Annual Report, 2022-2023).

Our company supplies and maintains equipment utilised in such mines, and as such we have had a direct interest in identifying and reducing the risks associated with our equipment’s operation. Analysis of the 2021 and 2022 accident statistics indicated that the second and third highest incidence of accidents occurred in locations where our equipment works, shown highlighted in Figure 2.

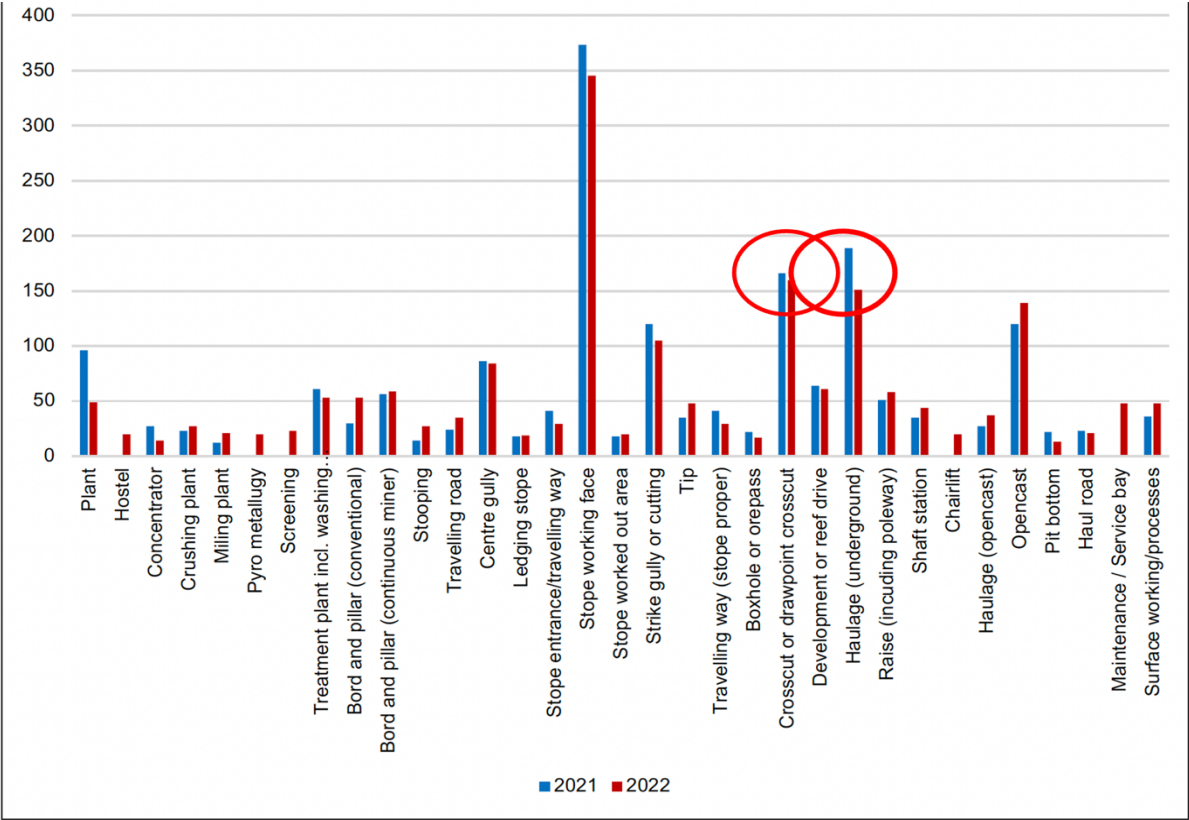


Figure 2. Accidents classified by location (Mine Health and Safety Inspectorate Annual Report, 2022-2023)

Haulages and crosscuts in deep-level mines are considered high-risk areas because of the inherent hazards listed in Table I, sometimes exacerbated by poor housekeeping.

Table I. Hazards in haulages and crosscuts

Inherent hazards

- Small dimensions (typically 3m x 3.5m)
- Heavy mobile equipment
- Electrical reticulation at lethal voltages
- High rock stresses
- Heat and dust

Housekeeping related hazards

- Poor underfoot conditions and tripping hazards
- Low lighting levels
- Inadequate ventilation
- Sub-standard track laying
- Excessive water in footwall

The area in the haulage with the most inherent risks is the development end, which is repetitively drilled, blasted, cleaned, and roof bolted, usually on a daily cycle. As such, it is a location prone to accidents, for which reason the development end, and crosscuts, refuges, and other underground spaces being developed require special attention.

Table II. Additional hazards in the development end

Inherent hazards

Exposed rockface
Unsupported hanging wall (roof)
Excessive heat
Water and gas ingress
Blasting fumes

Potential procedural and blasting hazards

Uneven footwall and low hanging wall
Misfires
Non-level temporary rails
Inadequate ventilation
Excessive water from drilling and cleaning

To capture all the risks associated with the equipment working in these locations we developed the six-step procedure described below, which systematically assesses risks in the local environment, the process whether drilling, loading or tramming, and the equipment itself.

The Six-Step design procedure minimises risk

In this paper we propose the six-step 'Zero Harm' procedure as a practical method for redesigning underground equipment to minimise risk to the operator and reduce equipment damage.

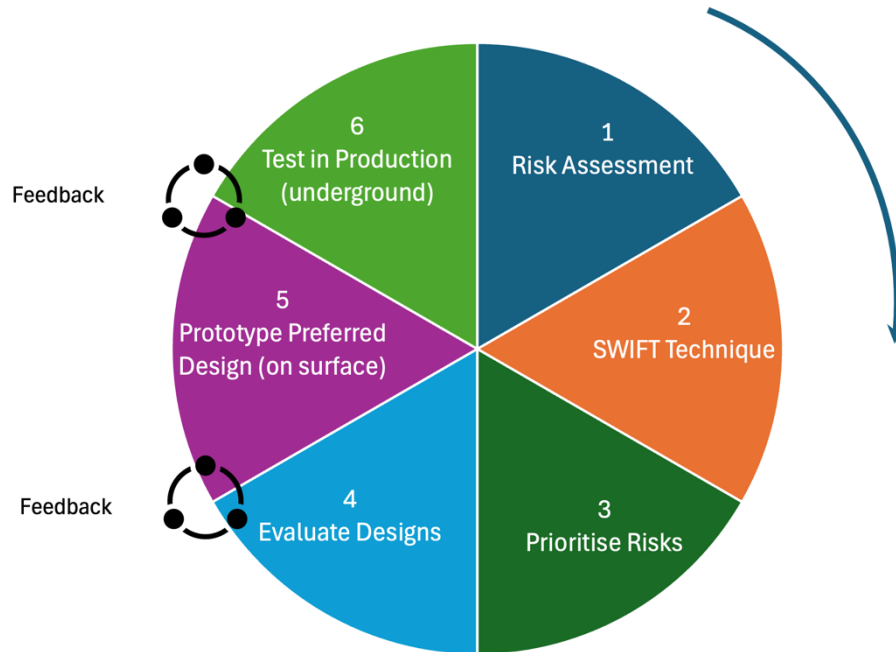


Figure 3. The six-step Zero Harm design procedure to minimise risk.

Step 1 is a risk analysis to identify:

- a) the inherent global and local environment hazards.
- b) the hazards associated with the specific process in which the equipment is utilized.
- c) the hazards associated with physically operating the equipment in that process.

Step 2 involves undertaking a Structured What-If Checklist Technique (SWIFT) analysis, used by the United Kingdom defence force amongst others (ASEMS online, SWIFT).

SWIFT systematically evaluates, risk by risk, the consequences of accidents that might result from the manifesting of the risks identified in step 1. It evaluates the likely effect of their occurrence on the safety of the equipment operator as well as damage to equipment utilised in the operation, as illustrated in Figure 4. It is also a useful tool in the Risk Awareness training of mineworkers.

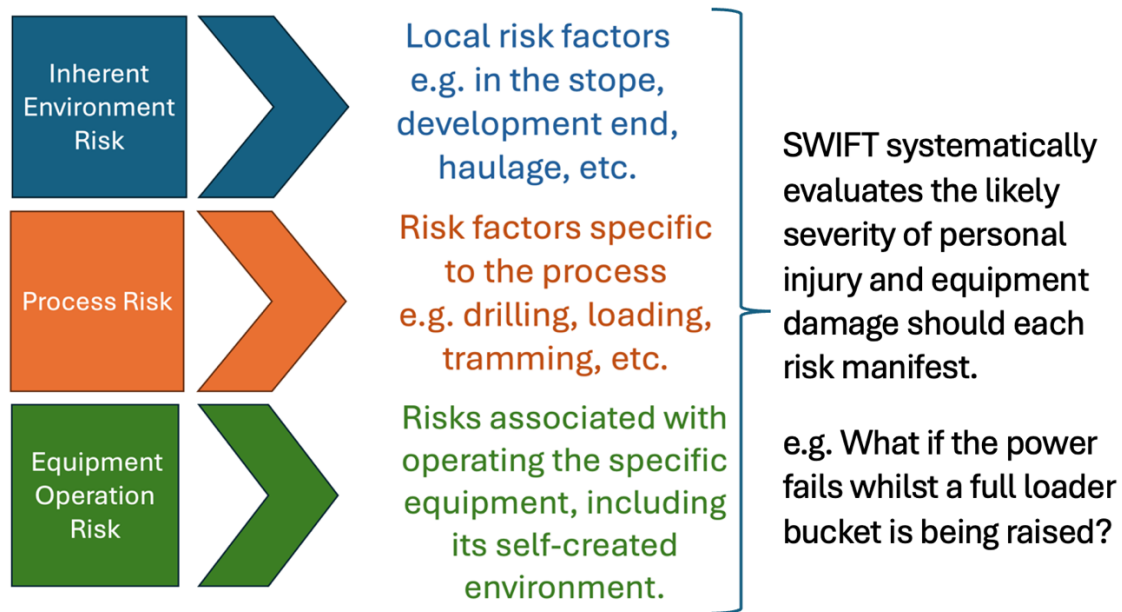


Figure 4. SWIFT evaluates the potential severity of each risk.

The SWIFT methodology not only identifies the risks inherent in process or equipment design, but also highlights risks arising due to negligence, non-adherence to standard procedures, poor housekeeping, lack of equipment maintenance, equipment sabotage, or operator incapacity.

The what-if questions stimulate debate between relevant persons as to how best solve a particular risk, whether by change in method, standard procedure, inspection frequency, equipment design or a mix of these.

Table III. Examples of What-If questions

Risk category	What-If
The environment	A drill-rig operator suffers heat syncope (fainting or dizziness) whilst operating the machine in an excessively hot development end?
The process	A locomotive derails traversing an overly tight rail track radius?
The equipment	The rifle-bolt has been removed from a pneumatic throw loader?

Step 3 prioritises the most serious risks evaluated in step 2, thus ranking the design objectives to eliminate or minimise the most serious risks first. The ranking method shown in Tables IV and V aims to quantify the severity of each risk based upon previous occurrences, its potential to cause injury or damage, and the probability of such accidents occurring in the future. The scores and grades shown are indicative of risk severity but can be adjusted by management to suit circumstances between and within mining operations.

Table IV. The risk grading scores based upon previous occurrences

RISK SCORES					
Prior Occurrence (F)		Severity (S)			Reoccurrence (P)
Frequent ≥ 4	3	Catastrophic	Multiple fatalities	8	Likely 3
Occurred ≥ 1	2	Disaster	Fatality/ $\geq$ R1M damage	7	Possible 2
Could occur	1	Very Serious	Reportable $\geq$ 14 days	6	Unlikely 1
		Serious	Reportable < 14 days	5	
		Important	Injury/ $\geq$ R20,000 damage	4	
		Of concern	$\geq$ R5,000 damage	3	

Total severity score = F x S x P

Table V. Priority determination for process and equipment design

DESIGN/RE-DESIGN PRIORITY			
Score	Grade	Risk Potential	Design/Re-Design
≥ 41	AA	Disaster/Catastrophic	Essential - Immediate
21 to 40	A	Major	Necessary – ASAP *
11 to 20	B	Serious	Urgent – next overhaul
1 to 10	C	Minor	If practical

* as soon as possible

An example of risk prioritisation is shown below.

A fatal accident occurred in July 2017 at mine A when a loader operator was crushed against the excavation sidewall whilst loading under a box front.

A further fatal accident occurred in November 2017 at mine B when a loader operator was similarly crushed against the excavation sidewall in a development end.

These fatalities occurred more than once due to a particular risk or combination of risks. The probability of recurrence is likely without a change in process, standard procedure or equipment design. From Table IV the cumulative risk score is therefore:

$$2 \times 7 \times 3 = 42$$

which in Table V is rated as an AA risk, requiring immediate attention.

The above real-life example and others led to loaders being fitted with anti-topple devices, and in our case also being redesigned to be operated remotely as described under 'Implementation' below.

Step 4 evaluates different design concepts to minimise the identified risks, e.g. anti-topple vs remote control, and to achieve any other objectives, which might include changing the source of energy (e.g. from pneumatic to electricity), boosting productivity, simplifying maintenance, improving maintainability, etc.

Step 5 involves prototyping the preferential design on surface, eliciting feedback from mine managements, operators and maintenance technicians, and amending the design as deemed necessary.

Step 6 is the production test phase, where the loader is tested in an underground production environment, during which time any issues with its operation are noted and the design adjusted if necessary to maximise the safety and reliability of production models.

Implementation

We implemented the six-step Zero Harm procedure to determine the Salzgitter loader redesign priorities. When evaluating its operation in the development end and crosscuts, we concluded that

operator proximity to the loader was the primary hazard, and our priority was therefore to distance the operator from the loader. This necessitated either a tethered or wireless remote-control system. Both were developed and tested on surface and underground, with the most convenient and reliable proving to be the wireless remote control.

In parallel with risk reduction, and with rising energy costs in mind, we decided to redesign our loaders to not just be inherently safer, but to run directly off electricity, thereby eliminating the energy wasted when using compressed air as a power source, which has predominated for decades. We accordingly expanded the risk analysis to include the potential risks of powering the loader from an electric energy source instead of using compressed air.

By following the six-step Zero Harm procedure, we produced the safer, higher- performing and more cost-effective Salzgitter EL300R remote-controlled all-electric loader, the safety and operational benefits of which are summarised in Table VI.

Table VI. Safety and operational benefits of the redesigned loader

Design feature	Risk minimised	Benefits
Remote control the loader	Operator being crushed or injured by falling rocks	a) Operator stays under roof support a safe distance from the loader. b) Operation less physically demanding facilitating women operators, thus supporting the <i>Develop Women in Mining programme</i> (Mine Health and Safety Council Annual Report, 2022-2023)
Convert to all-electric loader with the following features:	High energy consumption (economic risk).	+40 times reduction in electrical power consumption.
Quiet operation.	Operator becoming deaf.	Electric loader runs -80db quieter than a pneumatic loader.
Electric slewing.	Oil contamination	Eliminate the use of oil in the loader.
Failsafe braking.	Bucket dropping if power fails.	Prevents potential injury and loader damage.
Multiple electrical safety features.	Electric shock and equipment malfunction.	a) Includes emergency stops both on the machine and remote control. b) Warning lights and audible alarms. c) Automatic stop if electrical limits exceeded (under/over voltage, E/L failure, etc.).
Multiple spotlights.	Poor illumination.	Enables operator to clearly see working area and detect hazards.
Single operator control.	Non-approved operation.	Only the approved operator can operate the remote-control handset for a specific loader.
Excess capacity, high torque motors.	Heat generation.	The loader runs cool throughout the loading cycle.
Environmental data measurement*.	Unsafe operating environment.	Temperature, humidity, presence of gases, dust, etc. can be measured, transmitted, and warning alarms given if maxima are exceeded.
Uneven rail detection*.	Loader toppling.	Audible or visible warning if the loader tilts too far to one side.
Personnel proximity alarm**.	Loader approached by non-authorised persons.	An alarm sounds on the equipment and person if an unauthorised person approaches too close.
* Future option	** Installed by mine	

A further economic benefit is that the EL300R is a straightforward factory conversion of the widely used HL380U pneumatic loader, and mines can upgrade their existing fleets, level by level, each conversion including a complete machine overhaul.

EL300R loader test phase

The loader was initially tested through several hundred loading cycles at our factory testbed, during which time several adjustments were made to improve safety and operational performance. In particular,

- a) The bucket cheek profile was redesigned to lessen the possibility of rocks bouncing out of the hopper when almost filled.
- b) The slewing mechanism was changed from hydraulic to electric actuation, to remove the potential for oil leakage, thus making the loader all-electric.

Testing the loader underground has been very successful to date, with no design amendments required.

Reducing the rerailing risk

When investigating the risks associated with the loading operation, it became clear that rerailing loaders, locomotives and hoppers had resulted in many injuries as shown in Table VI (Mine Health and Safety Inspectorate Annual Report, 2022-2023). This is clearly a hazardous operation and equipment derailling occurs frequently, usually because of track misalignment and sometimes obstructions on the track. It can also result in lengthy delays, particularly when it occurs some distance down the haulage, and would be classified a Grade A risk.

Table VI. Fatalities and injuries associated with development ends and crosscuts in 2021 and 2022

Equipment	Fatalities	Injuries
Mobile drilling machines (all locations)	1	39
Rocker shovels	1	19
Rerailing devices	0	25
Sub-total	2	83
Environment		
Dust, gas and fumes (all locations)	4	
Falls of ground		
Gravity (all locations)	21	503
Total	27	586

To address zero re-railing risk, we accordingly developed the *Hercules Re-railer* which is a two-person rerailing device that is easy to install and enables the operator to safely stand way from the machine whilst raising it. Its geometry is such that it automatically centres the machine back on the rails without requiring an external lateral force. It is a safer alternative and minimises delays.

Environmental and procedural risks necessitate continuous management

Whilst improvements to the loader have very significantly lowered the risks to operators, attaining zero harm requires environmental and procedural risks to be continuously managed to minimise injuries and loader damage in the haulage, development end and crosscuts. These include:

- a) Consistent housekeeping in the developing haulage, including the timely removal of tripping hazards.
- b) Adequate ventilation to keep the ambient temperature within acceptable limits and remove remnant blasting fumes and any gases emanating from the rockface.
- c) Effective barring of the hanging and sidewalls.
- d) Roof support to procedural specification and kept as close to the face as practicable.
- e) A level footwall so that the loader does not tilt to one side when loading.
- f) Secure and safe electrical reticulation to the loader.
- g) Adequate water drainage in the footwall.

CONCLUSION

Implementing the six-step Zero Harm procedure has resulted in a remote-controlled loader with significant safety benefits that minimise the risks identified in the environment and loading process, and which importantly ensures the operator is distanced from the hazards associated with manually operating the loader. It also prompted an evaluation of the loader's power source, which resulted in its conversion to an all-electric loader, with enhanced safety, performance and operating cost benefits. This methodology can be employed by any equipment manufacturer to systematically evaluate and eliminate or at least minimise the risks associated with the operation of its equipment, whether underground or on surface, and is also an effective tool to decide upon equipment type and features during the equipment acquisition process (ASEMS online, About ASEMS).

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Edward (Ted) Adlard

Chairman
Salzgitter Mzansi (Pty) Ltd

Commenced career as an engineer at Durban Roodepoort Deep gold mine, progressing to manager of Wolvekrans Colliery, during which time I was elected a Fellow of SAIMM. Currently chairman of Salzgitter Mzansi (Pty) Ltd, a manufacturer of hard rock mining equipment with a strong presence in the underground platinum mines.

AI-assisted geophysical safety measurements in underground mines

T. Schicht¹, S. John¹, S. Lüning¹, and B. Kratz²

¹K-UTEC, Germany

²Castalytics, Germany

Safety is of utmost importance in underground mining. Geophysical methods help to create a safe work environment inside the mines. In this paper we present

(1) seismic monitoring and (2) roof radar measurements supported by artificial intelligence (AI). K-UTEC has more than 50 years of experience in seismic monitoring for underground mines worldwide. Castalytics specialises in AI- assisted solutions for the mining industry.

INTRODUCTION

Underground mining and rock extraction may cause changes in stress regimes, resulting in instability in the subsurface and at surface. In extreme cases, this may lead to accidents with injuries and structural damages. Consequently, it is required that mining operators have a full overview of stress and strain levels in the subsurface at all times. A variety of monitoring and safety checks have been developed that help to ensure that mines are fully controlled and stable. Traditionally, some of the tasks are very time-consuming. The introduction of artificial intelligence (AI) and machine learning (ML) to almost all fields of human activities also provides opportunities for optimisation in the mining sector. AI and ML will speed up data processing and will improve the decisions resulting from such analyses. In this paper we will present applications in the fields of seismic monitoring and roof radar for underground mines.

AI is slowly finding its way into seismology (Dadhich 2023; Jiao and Alavia, 2020). For example, AI models can distinguish between different types of seismic events, such as earthquakes, volcanic activity, or human-induced seismic events (like mining explosions). This helps to better understand the underlying causes of seismic events. Furthermore, AI can be integrated into seismic networks to continuously monitor data streams and send alerts when potential seismic threats are detected. This real-time processing capability is crucial for timely disaster response.

Seismic monitoring is the ideal technology to continuously monitor a mining asset in all three dimensions. Areas of elevated geomechanical stress can be readily identified and mitigated by the mine's control centre. Staff can be evacuated and unstable tunnels be stabilised or backfilled. Instantaneous alerting of hazards is carried out automatically based on carefully chosen parameters. The results are subsequently checked manually to assure the highest quality and precision. K-UTEC runs a 24/7/365 worldwide seismic monitoring service that covers mining countries worldwide. K-UTEC has developed highly reliable seismometers for surface, underground mine and borehole measurements. Robust equipment reduces downtimes and avoids data gaps. The measured data are transferred by wire or WiFi out of the mine to a data logger which sends the information to the cloud for immediate processing and evaluation (Figure 1). K-UTEC plans, installs, operates and maintains seismic monitoring systems for a large number of international clients, supported by local partners. Annual and quarterly seismic monitoring reports present the results as part of a statistical analysis that can be used as a basis for geomechanical management decisions (Figure 2).

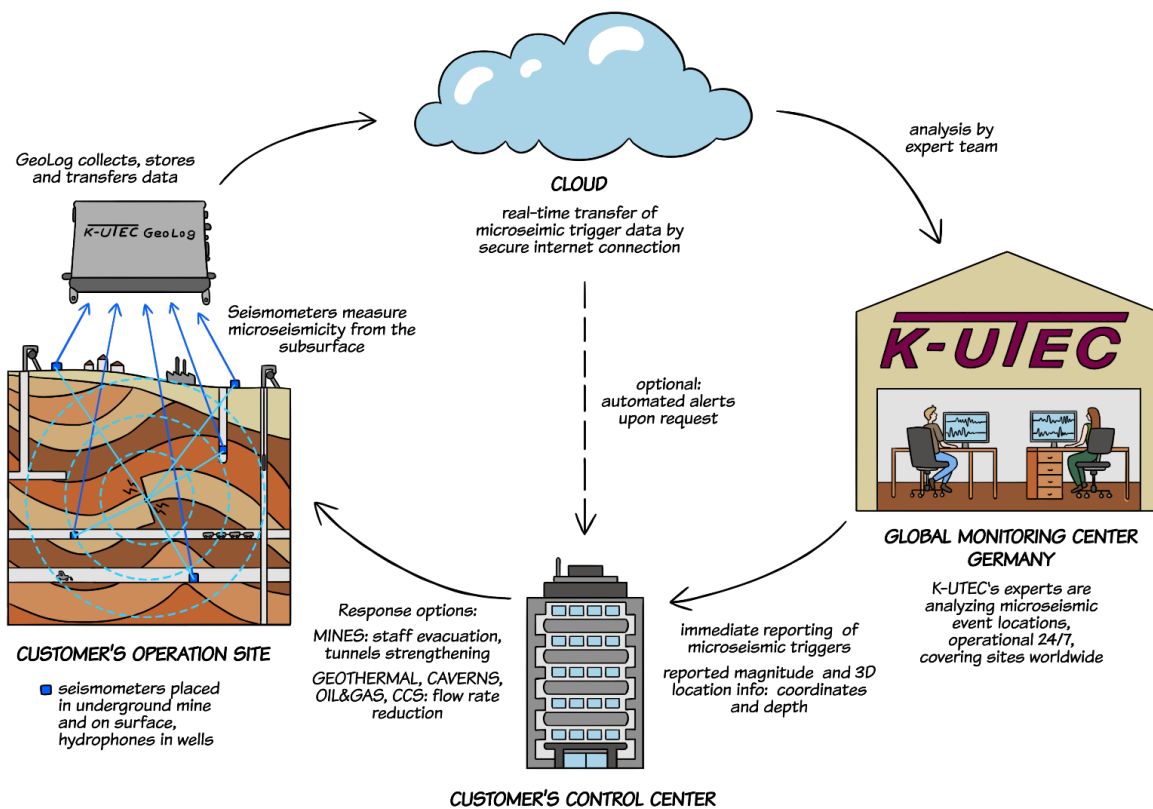


Figure 1. Measurement and alerting system for seismic monitoring.

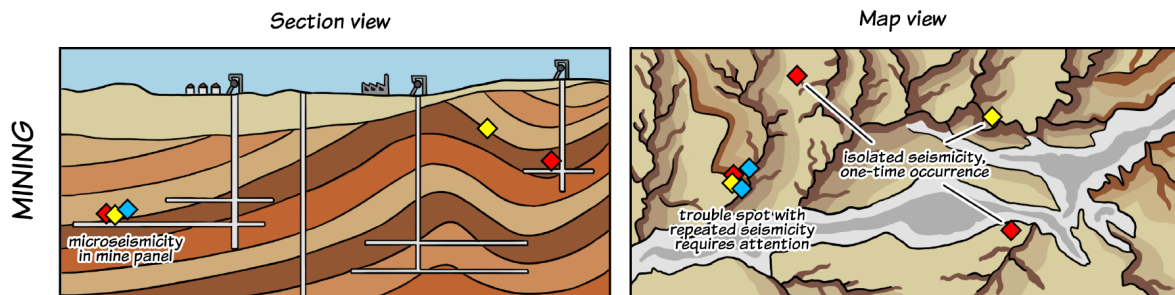


Figure 2. Colour-coded distribution of seismic events over time in section and maps view.

The seismometers not only detect seismic incidents from the underground rock volume; the sensor also registers other vibrations, e.g., originating from blasting, truck movements and even strong wind movements at ground surface. The measured seismological data has therefore to be effectively filtered to eliminate all signals that were produced from sources unrelated to the rock stress regime. The filtering can be very time-consuming and can be supported by well-designed ML algorithms. The particular challenge is that the filter must not cut out any of the genuine seismic events, yet must eliminate as much of the 'noise' as possible. This requires intense calibration which takes the local conditions of the different mines into account. AI will help to make the filtering and calibration even more effective. This will ultimately allow seismologists to spend less time on routine tasks, allowing them to concentrate on more advanced activities.

ROOF RADAR WITH THE SUPPORT OF ARTIFICIAL INTELLIGENCE

Roof radar is a geophysical method for the detection of cracks and loose material in the roofs of drifts and workings within a mine (Molinda *et al.*, 1996) (Figures 3-6). In the past, a significant number of workers have been tragically killed by roof rockfalls. Regular roof radar measurements are therefore essential. The electromagnetic method can be carried out at high measuring speed along roadways, either manually or automatically. Best results are achieved using a particular frequency range of radar waves that is suitable for the task.

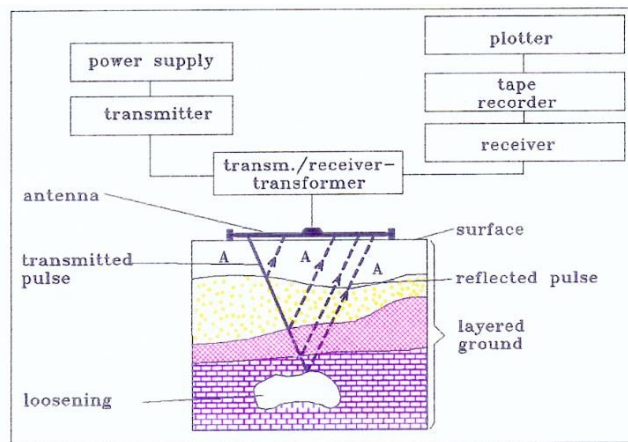


Figure 3. Radar principle.



Figure 4. Example of handheld measurement



Figure 5. Machine-supported measurement with three antennas in parallel.

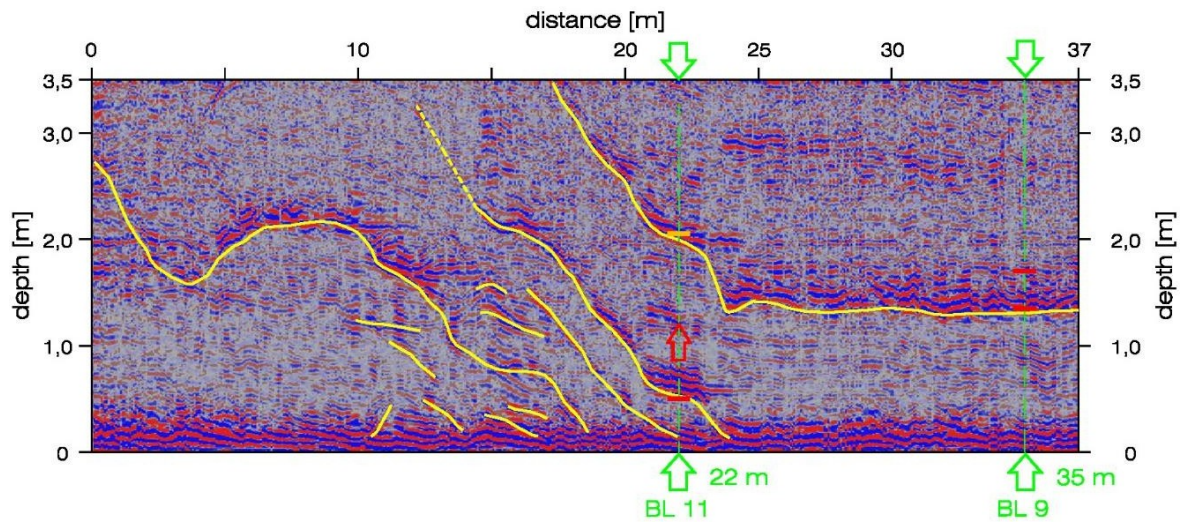


Figure 6. Interpreted result of a roof radar measurement.

In order to speed up the evaluation of the radar results and to simplify interpretation, Castalytics, supported by K-UTEC, carried out a study based on a traffic light system that facilitates evaluation and enables analysis by non-geophysicists (Figs. 7, 8). The evaluation is powered by AI, which was trained and parameterised with the help of many individual measurements and associated manual evaluations.

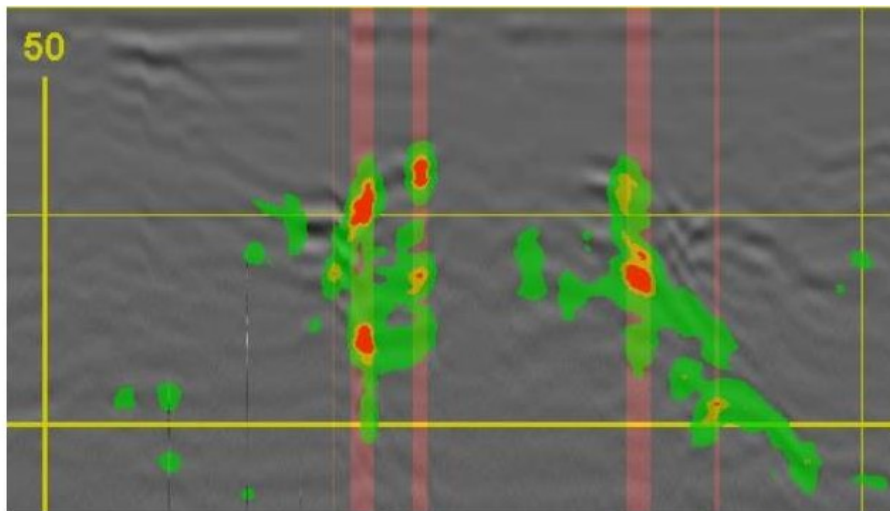


Figure 7. Automatic detection of dangerous zones powered by AI.

Red	Obvious anomaly
Orange	Possible anomaly
Green	Improbable anomaly
Grey	No anomaly
Bright red	Visual aid to make it easier to assign distances to a certain distance along the measuring section

Figure 8. Traffic light system of the AI-supported detection of the radar anomalies

CONCLUSIONS

ML and AI are gradually entering into mining processes. It is clear that although these new developments will not replace key activities in the mines, they will help certain operations to be faster, safer and more effective.

We have presented two applications in seismic monitoring and roof radar. Many other applications will benefit from this new technology. Mining operators will have to continuously survey the technological advantages of ML and AI and gradually apply them in their working routines. Other mining operators will clearly do the same and may obtain a competitive advantage if this innovation is ignored for too long.

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Dr. Sebastian Luening

Executive Director
K-UTEC

Sebastian studied geology at the University of Göttingen and received his PhD and Habilitation degrees from the University of Bremen. Sebastian has been employed in the natural resource sector for 25 years, initially in oil and gas, now in mining. He previously worked for Lasmo in London, RWE Dea in Hamburg and Galp in Lisbon. He has extensive project experience in North Africa, Arabia, Sub-Saharan Africa and South America. Today, Sebastian serves as Executive Director at the mining engineering company K-UTEC where he is responsible for the mining and geoscience departments.

The dynamics of and limits to reliability-based safety management in complex socio-technical systems: A mining industry case study of safety rule violation behaviour

T. Mariri and A. Odendaal

Stellenbosch University, South Africa

Study Background

The reliability-based approach to the control of risk is largely informed by authoritarian high modernism¹, that is, a “strong belief in scientific, technical and managerial expertise, particularly through stronger and stringent administrative ordering”. Also referred to as Model 1 approach or Safety-I approach, the approach is driven by the view that safety rules must be formulated by competent experts and serve the primary purpose of protecting the system from the potentially fallible sharp-end operators.

Safety rules, as the operational work system level representation of the safety management system, are designed and implemented to improve safety through controlling employees’ performance variability. Rules are essentially meant to create a structural environment within which organisations’ productivity goals are or ought to be safely pursued by the system actors, particularly those tasked with the responsibility of carrying out or supervising production. However, because organisations are complex dynamic emergent socio-technical systems, the influence of safety rules on employees’ behaviour and, by extension, on safety is also complex and dynamic. As self-determinists, employees continually make planned behavioural choices, including choices related to non-compliance with safety rules.

The employees’ behavioural choices, in complex dynamic socio-technical systems, are, however, not random but a function of the structural environment created by the very system, under the custodianship of the system’s architects, the organisation’s management.

Essentially, therefore, employees’ inherent human need to exercise behavioural discretion presents an uncomfortable management dilemma. On the one hand, the organisation’s management ought to exercise its formal and legal prerogative, as well as the responsibility for safety rule design and enforcement. On the other hand, management also ought to accept the reality that, in complex dynamic socio-technical systems, safety rules are not all followed and/or followed in the manner intended by management as the rules custodians. Management’s safety rule design and enforcement hegemony is continually challenged by employees’ own self-determined safety rule compliance choices.

Modelling methodology.

The dynamic complexity of the safety rule violation behaviour (SRVB)-safety management dilemma was modelled through a single case study design (a single mine operation) and system dynamics causal loop modelling methodology.

Modelling results.

The complex, dynamic interaction of well-intended management strategies and/or choices aimed at achieving various strategic goals of the case study mine were, from the empirical evidence, found to create what system dynamicists referred to as the system of forces that creates a problem, SRVB in this case, and continues to sustain it. The findings provides evidence-based insights into the limits to reliability-based safety management and creates the foundational basis for alternative, systems thinking, resilience-based safety management approaches.

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Tendai Mariri

Lecturer
Stellenbosch University

Tendai, a registered Industrial Psychologist with the Health Professions Council of South Africa (HPCSA), is a Lecturer and Researcher in the Department of Industrial Psychology, Faculty of Economic and Management Sciences at Stellenbosch University. He holds a Masters' degree in Industrial Psychology (Fort Hare University) and is completing a PhD in the same discipline (Stellenbosch University). He holds a professional certificate and is a Danida fellow in OHS (COWI/DFC, Copenhagen). Mariri's research interests are broadly in sustainable development, labour matters, including decent work and corporate sustainability. His research specifically focuses on safety, in particular, the application of system dynamics to model and seek sustainable solutions to dynamic and complex safety behaviour-safety management challenges of high-risk industries. Tendai has published research articles in journals and has presented at various national and international conferences

Is the mining industry ready to embrace virtual reality?

M. Hocker

Boiler Room, South Africa

INTRODUCTION

For over 25 years, The Boiler Room has pioneered advancements in 3D computer animation, eLearning, maintenance solutions, and accident reconstruction within the industrial and mining sectors. Recognising the need for innovative approaches in training, we have embraced virtual reality (VR), creating over 100 VR experiences that reimagine learning for a new era. Through more than 100 successful VR simulations currently deployed, we are witnessing a fundamental shift in training methodology, transforming traditional learning into interactive, immersive environments uniquely crafted for the mining industry. Our offerings include advanced VR maintenance systems, trackless mobile machinery (TMM) simulators, and fully immersive 'A Day in the Life' experiences that give trainees a real-world sense of working in hard rock and soft rock mines. Such applications bridge theoretical knowledge and hands-on practice, immersing employees in simulations that enhance knowledge retention and operational competence. Despite VR's promising benefits, adoption within the mining sector has been uneven, challenged by content quality, skill-level usability, high costs, hardware limitations, and practical issues like motion sickness. These factors have led some industry players to question whether VR can genuinely meet the mining industry's complex training needs.

A Visionary Leader: The Role of Mark Hocker

The founder of The Boiler Room, Mark Hocker, has been pivotal in helping organisations navigate VR's complexities in mining. Drawing on extensive experience, he works alongside companies to separate effective VR applications from ineffective ones in this fast-evolving space. By introducing comprehensive mixed training methodologies, Mark provides a framework to improve team safety, skill-building, and overall training efficacy. His leadership brings clarity to the industry's central question: *Is the investment in VR justified for mining?*

Understanding the Mining Workforce

Assessing VR's value for mining requires understanding the workforce's varied backgrounds, skills, and generational diversity. Training materials that engage semi-skilled workers may not resonate with more technically educated employees, and VR adoption may vary between age groups, as older employees often find the technology challenging, while younger workers adapt more readily. Addressing these differences enables a tailored VR approach that can foster better engagement and retention across workforce segments, driving improved training outcomes and job satisfaction.

A Detailed Primer on Virtual Reality in Mining Training

Defining Virtual Reality

VR, while commonly envisioned as a headset experience that immerses users in a digital world, offers a much broader array of tools. At The Boiler Room, VR extends across multiple devices and platforms, including smartphones, tablets, 360° videos, WebGL, and traditional MS Windows VR systems, each suited to unique training needs. Understanding the nuances of each VR medium allows mining companies to implement training solutions that cater to specific scenarios, enhancing the technology's effectiveness in addressing various training requirements.

1. **Smartphones, Tablets, and Touch Screens**

These devices use intuitive, touch-based interfaces that make VR experiences accessible through simple taps or swipes. Learners interact with training content by navigating digital environments or manipulating objects with touch commands, allowing for on-the-go learning and rapid information retrieval. Visual guides like crosshairs highlight interaction points, directing users' attention and enhancing their experience. This medium is particularly beneficial for short, focused modules that miners can access in on the job with mobile devices.

2. **360-Degree Video and Photographs**

Offering stationary visual exploration, 360° videos and photographs allow users to explore environments without physically moving. This format functions as a virtual sphere in which users stand at the centre, observing their surroundings in every direction. Informational overlays add context to specific elements, enabling workers to understand mine layouts, equipment, and safety protocols before entering these environments physically. Such familiarisation helps improve worker preparedness and reinforces safety protocols in a low-risk setting.

3. **PC Platforms with MS Windows and WebGL**

Desktop-based VR platforms provide a more immersive experience, supporting complex simulations with navigation tools like keyboards and mouse or joysticks. Trainees can engage in intricate exercises, such as operating heavy machinery or understanding the mechanics of a diesel engine. The interactive, game-like nature of these platforms significantly enhances training outcomes by replicating the real-world challenges miners face, thus creating memorable and practical learning experiences.

The Essence of True VR

True VR, often referred to as a 'digital twin', aims to replicate real-world environments with remarkable accuracy, facilitating training that is as close to actual scenarios as possible. A digital twin serves to enhance training fidelity by allowing employees to interact with realistic settings, offering a safe but deeply immersive environment where they can build practical skills and explore new situations.

For example, creating a digital twin of a boardroom involves replicating critical elements to ensure that the virtual space mirrors its physical counterpart as closely as possible:

- **Lighting Conditions:** Realistic simulations of lighting and shadow, replicating the room's lux levels contribute to the environment's authenticity and affect how learners perceive and navigate the space.
- **Textural Accuracy:** High-quality photographs of textures, such as walls, floors, and furniture, are applied to the 3D models, ensuring materials like wood grains and finishes are represented accurately.
- **Detailed Replication:** Every item in the room, from furniture and equipment to smaller details like coffee machines, is recreated, giving learners a seamless sense of reality in the virtual setting.

While absolute accuracy may be difficult to achieve due to practical constraints, creating high-fidelity VR environments is critical to ensuring that VR meets specific learning objectives effectively.

VR Applications in Mining: A Comprehensive Overview

With a foundation in VR's capabilities, we can explore its practical applications across multiple training areas in the mining industry. VR transforms traditional training into engaging, hands-on simulations, covering a range of scenarios from safety protocols to equipment maintenance, enhancing both effectiveness and trainee engagement.

Safety Protocols

One of the most essential applications of VR in the mining industry is safety training. VR's immersive simulations allow employees to experience emergency scenarios and practise response strategies

without exposing them to real-world risks. This safe yet realistic approach ensures that miners can build the skills and confidence needed to handle crises effectively.

For instance, VR enables miners to practise barring and scaling procedures within a simulated underground environment. Using a virtual 1.8 m pinch bar, they can refine their techniques for proper grip and movement without risking a dangerous fall of ground. This simulation closely mimics the real-world task, allowing employees to become proficient in critical safety actions without any physical hazard.

As where a safety campaign speaks to the entire mine and lends itself to mass media marketing such as videos, posters and toolbox talks. This can be bolstered with eLearning and VR.

Accident Reconstructions

Accident reconstructions are a highly effective application of VR, enabling mining teams to analyse past incidents and derive critical safety insights. While traditional video can convey basic details of an accident, VR elevates this learning experience by allowing trainees to explore reconstructed scenes interactively. This immersive approach enables a deeper understanding of incident causality, reinforcing lessons that are more likely to prevent future occurrences.

VR accident reconstructions often start with 3D scans of the incident site, which are then integrated into Windows-based VR or touch screen VR environments. These reconstructions allow facilitators to guide learners through the sequence of events, offering detailed insights into the conditions and factors that led to the incident. Typically, all personnel are omitted from the reconstruction to focus solely on environmental and procedural aspects of the scene.

A notable example involved a client who faced an accident with a union supervisor, the latter claiming they were wearing a seatbelt when a truck rolled over, resulting in an alleged head injury from the side window. Using VR, the scene was recreated twice: once with the seatbelt on and once without. By applying real-world physics and gravity, the VR simulation demonstrated that breaking the side window was only possible if the seatbelt was not worn, thus clarifying incident details and reinforcing the critical importance of seatbelt use.

1. Geological Hazard Training and TARP

Effective mining operations hinge on the ability to identify, classify, and address geological hazards, making this a critical focus for trigger action response plans (TARP). Accurate hazard assessment and response are essential, particularly for lower-skilled workers who require clear, practical training methods.

VR and 360° eLearning provide an immersive and interactive approach to geological hazard training that goes beyond conventional eLearning or static image-based instruction. By allowing workers to visually explore potential hazards in a lifelike environment, VR enhances comprehension and retention, making TARP protocols more accessible and effective across the entire workforce. This immersive training approach equips employees at all skill levels with the knowledge to respond swiftly and correctly to geological risks, supporting a safer, more prepared mining operation.

Trackless Mobile Machinery and Rail Operator Simulators

Traditional TMM training typically involves expensive simulators that use real machine cabs, with all the levers, buttons, and controls intact, placed in a computer-assisted virtual environment (CAVE). These setups surround the operator with screens on three to four walls to simulate a 180-360° environment, often with a motion platform to track operator data such as braking force. While effective, these simulators come with high start-up costs—often equivalent to the actual machinery—making them costly for widespread use.

A significant challenge with traditional simulators is the bottleneck they create, as trainees need extensive time on these machines to complete mandatory learning and certification, slowing down training throughput.

Newer VR technologies offer a more affordable and flexible alternative. By using VR goggles paired with controls that can be 3D-printed replicas of actual machinery, trainers can create immersive, realistic simulations on static platforms or motion rigs at a fraction of the cost. For instance, four to six VR setups can be implemented for the price of one CAVE simulator, increasing training capacity and making it possible to train multiple operators simultaneously.

While VR-based systems do lose some tactile feedback compared to real machinery, they work exceptionally well for certain models, such as the Sandvik DS211. Trainees use a remote-control replica for tasks like roof bolting, allowing them to practise from a safe distance.

Assessing Motion and Feedback Needs in VR Simulators

Whether to incorporate movement into VR simulators, such as with an expensive motion platform, depends largely on budget and training goals. For some operations, like tramming, experiencing every road bump may not be essential. The core training goal is more about mastering drilling accuracy and recognising the consequences of incorrect actions. Hybrid extended reality systems that combine VR goggles with real machinery controls offer a cost-effective middle ground, providing muscle memory training with tactile controls.

Emergency preparedness training is also an area where VR shines. Simulations can replicate critical scenarios – such as a hydraulic line rupture or a cabin fire – helping operators understand and respond to unexpected events without the physical risks of live training.

Collision Avoidance and Safety Modules

Collision avoidance systems (CAS) are now becoming mandatory, with Level 9 CAS modules available as simple add-ons to these VR simulators. Such safety features integrate seamlessly, ensuring trainees are well-versed in modern safety protocols.

Loco Operator Simulators

For loco operators, custom VR setups that include essential safety features like the deadman's switch are crucial. This control has saved countless lives and is essential for any VR environment training. VR also enables loco operators to use a remote control unit, allowing them to 'walk' around and control the loco from a standing position, giving a more comprehensive training experience than traditional seated simulators.

Standard eLearning still plays an important role in training operators on procedures such as Pre-Start Checks, Production Scheduling, Traffic Management, and Machine Appreciation. However, the flexibility and realism that VR brings to the table make it a powerful complement to traditional methods, especially for hands-on tasks and emergency response training.

Inductions and Standard Operating Procedures

Induction training in mining typically falls into two main categories: contractors and employees. For contractors, training is often most effectively delivered through videos, with clicker-style assessments if scoring data is required. Employee training is generally more varied, with semi-skilled workers using video and clicker assessments, while higher-skilled personnel benefit from videos embedded within eLearning modules.

Can VR enhance induction processes? Absolutely. VR simulations, whether through Windows-based setups or VR goggles, provide an immersive experience that enriches the induction process. At The Boiler Room, we've developed full-scale mock mines in VR for clients, replicating tasks as part of a 'day in the life' experience for miners.

In underground mining scenarios, VR can guide trainees from the bus stop to the security area, through safety testing, to the change house, lamp room, and finally into the cage and waiting area underground. These stages can all be represented within a multiplayer VR environment, with randomised events such as falls of ground or passing locos. The VR environment can also simulate real-world team dynamics by including members who may be unfit for duty, training the team to recognise and adapt to these challenges.

VR also supports SOP training by enabling employees to experience role-based scenarios. For example, in a conventional underground mining setting, a rock drill operator (RDO) might be absent. The VR simulation lets trainees explore how this affects team dynamics and productivity, learning to adapt their plans accordingly. Trainees can assume various roles, from RDO to assistant, scraper winch operator, or even team lead, not only to understand each role's responsibilities but to appreciate the challenges each team member faces.

This VR-based approach encourages a 'my brother's keeper' mindset, promoting teamwork and safety by simulating real production targets and allowing team members to practise looking out for one another. In doing so, VR training helps build both technical skills and a culture of mutual support and accountability in the mining workforce.

Rock Drill Operators Training

Training RDOs presents unique challenges, as these semi-skilled workers are often more receptive to hands-on tools than VR goggles. Traditional training methods for RDOs generally focus on classroom-based instruction combined with clicker systems for theory, followed by practical, physical drills.

While VR has limited direct application without specialised replicas like air leg and rock drill levers, it can add significant value in a supervisory context. For example, VR can enable team leaders to monitor a 3D VR character performing drilling actions. This virtual observation allows leaders to assess drill alignment and collaring, with correctly drilled holes marked in green and errors highlighted in red, much like the traditional 'broom handle' technique.

Additionally, VR simulations for RDO training can be pre-programmed to introduce random errors, such as issues with TARP, incorrect drilling angles, or the presence of methane pockets. This approach allows trainees to encounter and learn from potential challenges in a safe, controlled environment, preparing them more effectively for the complexities of real-world drilling operations.

Winder Simulators and Shaft Inspection Training

Sibanye Stillwater commissioned the development of a comprehensive VR goggle-based winder simulator, complete with replica controls from the winder house. This simulator includes both Siemens and ABB systems, accommodating both AC and DC winder operations. Operators learn not only to read and control cage and bell codes but also to 'read' the ropes through inspection windows located in the roof and walls. By observing the roof inspection window, trainees can determine if the cage is in the brake position with loose ropes, and by looking through the wall inspection window, they can estimate the cage depth based on rope levels on the drum.

The simulator also replicates emergency scenarios, enabling operators to practise responses to critical failure events, building their competence and confidence in extreme situations.

Shaft inspection training, essential for regulatory compliance, is also included in the VR training programme. Legal requirements dictate monthly shaft inspections, typically performed by highly skilled, four-person teams working late hours. Recognising the need for a broader pool of qualified inspectors, Sibanye Stillwater has introduced VR-based shaft inspection training, the first of its kind. Trainees gain an understanding of each team member's role and learn to identify and address signs of wear or damage, as well as how to repair guide rails and bunting. This innovative training has been highly successful in upskilling less experienced personnel, ensuring consistent and reliable shaft inspection across the organisation.

Medium Voltage Substation and High Voltage Yard Training

Sibanye Stillwater commissioned the development of a fully immersive VR-based simulator for medium voltage substations, mini subs, and transformers. While theoretical training remains classroom-based, practical assessments in this high-stakes area have posed significant safety challenges due to the hazards of handling 11 kV voltages.

In real-world scenarios, trainees must diagnose substation trips or connect new systems while wearing heavy arc suits and using long, cumbersome test probes. A single misstep could be fatal. The VR goggle-based system mitigates these risks by allowing trainees to practise these tasks repeatedly in a safe, controlled environment. This hands-on VR training enables learners to master the procedures and gain confidence before transitioning to live, high-voltage equipment, ensuring that they are fully prepared for the complexities and risks of the real-world setting.

Maintenance Training Solutions

Over the years, we have developed a range of innovative maintenance solutions, from mobile apps for smartphones, touch screens, and tablets to Windows-based eLearning and fully immersive VR goggle systems. These solutions, designed for mining companies and original equipment manufacturers (OEMs), have delivered significant success.

For example, in the coal industry, our eLearning and Windows-based VR training solution reduced unscheduled maintenance on a continuous miner's water flow system from 24 hours to just four hours. A major OEM in Finland implemented our interactive app—compatible with cellular phones, tablets, and touch screens and featuring VR components—reducing global workshop maintenance times on their machines by approximately 50%.

This field is rapidly evolving with advancements in artificial intelligence (AI) and augmented reality (AR). AI-powered predictive maintenance is enabling early detection of potential component failures, while AR headsets, such as Realware, offer hands-free, head-mounted guidance. These AR devices can also be preloaded with offline maintenance training, empowering workers to access procedural instructions wherever they are, enhancing efficiency and safety across maintenance operations.

CONCLUSION

While certain training needs in mining are still best addressed through traditional methods like videos, clickers, and eLearning, VR has emerged as the next frontier in training technology. Its immersive capabilities allow for unparalleled data collection, enabling companies to track hand and eye movements, assess performance in real time, and conduct comprehensive gap analyses for continuous improvement.

As VR technology advances, its potential to enhance training and safety in mining expands, offering a robust tool for risk mitigation and skill development. Mining companies that strategically incorporate VR will see gains in training efficiency, improved safety outcomes, and a more skilled, adaptive workforce. The Boiler Room is dedicated to setting the benchmark in immersive training solutions for mining, driving forward the industry's digital transformation and fostering a new standard of operational excellence.



Mark Hocker

Chief Executive Officer
The Boiler Room

Mark Hocker, founder of The Boiler Room, is a pioneering force in multimedia, eLearning, and 3D animation in Southern Africa and internationally. Originally from Sydney, Australia, Mark's career began with a degree in computer programming, excelling in languages like Cobol, Basic, and C. His early accomplishments in 3D animation caught the attention of top Australian television producers, leading him to create logos and special effects for prominent television channels and world-renowned music bands. He was also invited to lecture on 3D animation by the Australian Film and Television School.

At just 21, Mark had achieved remarkable success and travelled extensively, working with major UK networks such as the BBC, ITV, and Channel 4. Upon visiting South Africa, he saw untapped potential in 3D animation and introduced the technology to key institutions, including SABC, M-Net, and SAPS. He also developed and taught courses that became foundational in South Africa's animation education. In 1999, Mark established The Boiler Room, which has since become a leading content provider, specializing in high-end 3D animation, eLearning, and immersive VR and AR training. The Boiler Room is renowned for its innovative safety training and VR workplace simulations, which serve top clients across Southern Africa and beyond.

Assessment of the managers' certificate of competency part C examination during 2010-2019

N. Ndiweni and M. Mpanza

University of Johannesburg, South Africa

The Mine Health and Safety Act (MHSA) No 29 of 1996 introduced a statutory requirement for all mining operations in South Africa to ensure that they appoint competent persons to manage health and safety risks in the workplace. To enforce this requirement, the Department of Mineral Resources and Energy implements and controls the issuing of certificates of competence (CoC) for specific mining-related qualifications. These include CoCs for engineers, mine managers, mine overseers, and surveyors. The government-issued certificates of competence are notorious for their difficulty and high failure rate. It has been over 20 years since the first Mine Managers' Certificate of Competency (MMCC) was introduced but the high failure rate for this CoC persists and this is a concern for mining stakeholders. This paper examines the content of the MMCC examinations over a ten-year period to uncover what is frequently asked in this exam. A mixed-method approach was used, involving a literature review, content analysis of the MMCC Part C examinations, and the quantification of examination question types and patterns.

The key findings showed that examination papers had 63% of the questions being descriptive and 37% keyword-based. Candidates are required to be qualified and experienced before attempting the MMCC Part C examination. During examination preparation, candidates must compile a reading indexing system of the MHSA law book to guide their search for correct answers during the open-book examination. The researchers found this a helpful strategy to assist candidates in succeeding in the MMCC Part C examination and a comprehensive list of related topics are provided in this paper.

Keywords: MMCC Part C, mining examination, competence, MHSA

INTRODUCTION

Mining production activities use equipment, processes, systems, procedures, and innovative designs to cope with a dynamic physical environment. Occupational health and safety risks need to be considered throughout the process to ensure a safe, healthy, productive, and profitable work environment, as the mining industry is driven by the goal of 'zero harm'. Mining engineering practitioners thus have to be well versed in issues pertaining to mine health and safety as they are entrusted with the leadership role of ensuring zero harm in the workplace.

To carry out the role of supervising health, safety, and profitable mine production, experienced mining engineering practitioners must obtain a Certificate of Competency (CoC). This certificate provides the assurance that a practitioner is qualified and competent to deal with health and safety matters. The Mine Managers' Certificate of Competency (MMCC) Part C is a legal knowledge examination for potential candidates. The examination is based on the Mine Health and Safety Act (MHSA, 1996 (No 29 of 1996), including regulations made or deemed to have been made under this Act. The examination was regulated previously under the Minerals Act, 1991 and Mines and Works Act (MWA), 1956 (Act 27 of 1956), Section 9 of the MWA, which was not repealed by the Minerals Act, 1991 and the MHSA Amendment Act, 1997 (Act 72 of 1997).

The industry remains confronted with a high failure rate for the MMCC examination, which is a major concern for some mining stakeholders (Ndiweni & Mpanza 2018). This paper investigates the MMCC Part C examination questions and critically analyses the content of the examination. The MMCC Part C examination papers for the period 2010-2019 were reviewed to understand the frequently asked questions and to identify repeat questions. We anticipated certain trends in the manner of questioning and the type of questions asked. This paper is a follow-up to our previous study (Ndiweni & Mpanza 2018) on the factors contributing to the high failure rates for the MMCC Part C examination.

Background

A MMCC permits individuals to legally practice as mine managers at South African mines. A MMCC holder can be appointed to take up legal responsibilities at a mine, as stipulated in the Mine Health and Safety Act, 1996 (Act 29 of 1996), as amended and in its regulations (DMRE, 2020). There are two types of MMCCs issued for mine managers' competence: 1) the Mine Manager Certificate of Competency: Underground Coal Mines and 2) the Mine Manager Certificate of Competency: Underground Metalliferous Mines. There is little difference between the MMCC Part C examinations for the two certificates. Both examinations utilise the same question paper, comprising about seven questions and one choice question. For coal candidates, the questions focus on legislation applicable to coal mines; and for metalliferous candidates, the questions focus on legislation mainly applicable to large hard rock mines (DMRE, 2020).

The MMCC examinations and certificates are managed by the head office of the Department of Mineral Resources and Energy (DMRE). Prospective candidates apply to sit the MMCC Part C by contacting the secretary of the Commission of Examiners. The requirements for candidates to be eligible to write the MMCC examination are that they possess a blasting certificate, be at least 23 years old, have 500 shifts mining experience, and six months on the face (DMRE, 2020).

The MMCC examination consists of parts A, B, and C. There are exemptions for Part A and B for candidates who possess a Bachelor or BTech degree in mining engineering. Part C requires legal knowledge for the MMCC examination. There are two sets of examinations for MMCC Part C every year; one in May and the other in November. Both examinations are set at the same level but differ in content. This paper analyses only questions asked in the MMCC Part C examination over the last ten years as the majority of candidates write this section (DMRE, 2020).

The intention of this study was to investigate patterns in questioning and type of questions asked in the MMCC Part C examination. The primary objectives were to categorise the questions by classifying them according to their genesis and where answers can be sourced; and analyse the technical content of the MMCC Part C examination questions to identify patterns among them that could help aspiring candidates to prepare for the examination.

METHODS

A mixed-method approach was used in this study, entailing both quantitative and qualitative research approaches. The qualitative approach took the form of a literature review, and content analysis of examination papers, while the quantitative approach was an analysis of the MMCC Part C examination papers from 2010 to 2019.

The literature review involved searching for publicly available literature on the MMCC examination. This included international conference papers, peer-reviewed journal articles, theses, books, policy documents, guidelines, government publications, newspapers, and company reports. Primary themes and keywords were drawn from these sources and assisted the literature search process. Several academic databases were searched, including Google Scholar, Scopus, African Mines online, Engineering Village, Web of Science, and Geoscience World. Other internet sites visited included the DMRE website. Library catalogues were used to locate available material on the library shelves, and

additional databases were suggested by librarians. The keywords used in the search were limited to subjects concerning the MMCC i.e. “mine managers certificate of competence”, “government certificate of competence”, “legislation section of mine managers’ examination”, “Part C examination”, “mine health and safety”, “risks”.

The results obtained from the search were ordered according to the most widely cited. This was done to select the most relevant and valuable literature on the subject. The references obtained from journal article reference lists were pursued where relevant. The journal articles were located through indexing and abstracts of publications.

The content of the MMCC examination papers was analysed by categorising questions that had similar content and then assigning a code to each category. Four categories were established: group, type/format, question theme, and source of material. The categories are defined and discussed in the results section. These categories were identified from all examination papers from 2010 to 2019. The sample analysed in this study comprised a total of 299 questions.

RESULTS

On average, each examination paper contains seven questions, with the last two being a choice question for either coal or metalliferous mine candidates. In this study, we chose to analyse the questions that aimed at helping MMCC Part C candidates to read the MHSA book and source relevant documentation to prepare for the open-book examination. We did not analyse the choice questions for coal or metalliferous candidates.

Figure 1 shows the number of times the questions were observed covering a certain topic in the study period 2010-2019. The questions were divided into groups, based on the similarity of the topic or subject covered. The topics that featured most were flammable-gas related questions which appeared seven times within the study period. Flammable gas questions were related mostly to fiery mines; this approach is correct, because examiners must test the candidates regarding the dangers of methane gas and explosions and the precautions to be taken in fiery mines. Flammable gas was followed by procedures which appeared six times; penalties (appeals, offences, fines) appeared five times; and shafts, winders, and winches appeared also five times. Topics on duties featured as much as emergency preparedness which appeared four times each.

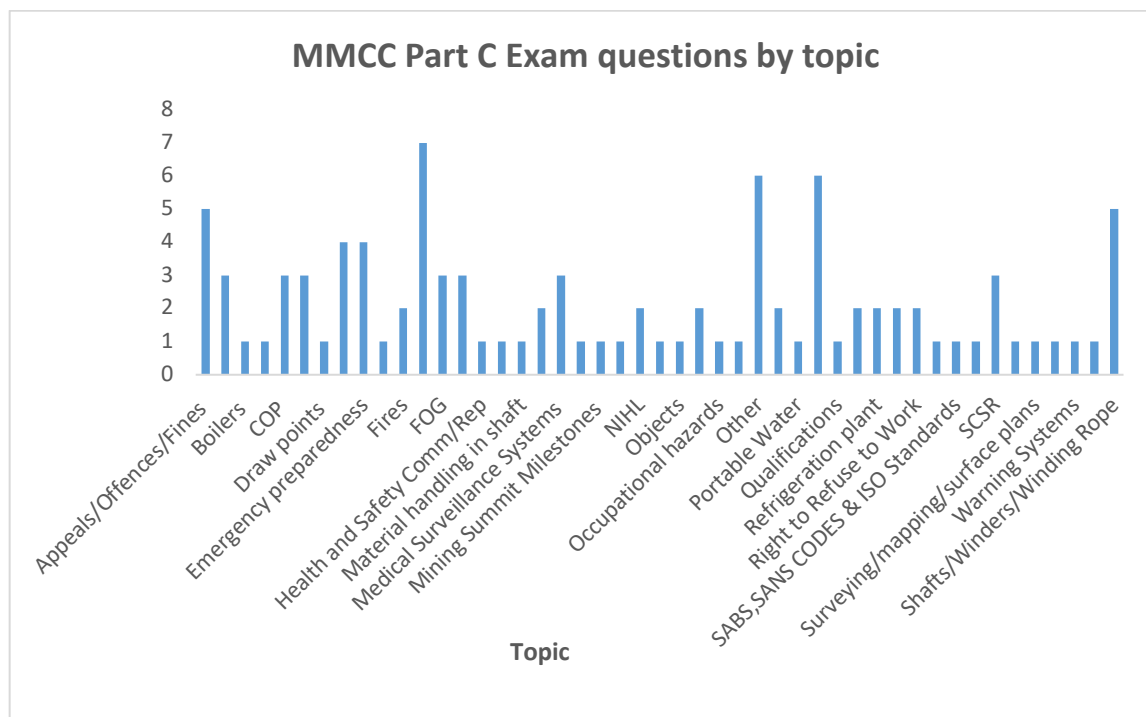


Figure 1. Number of questions grouped by topic.

We ascertained that there are two types of questioning. The first type of questioning is descriptive where candidates must draw from acquired knowledge to identify the inferred keywords in the MHSA and use those when answering. The second type of questioning is keywords where the candidate is directly given keywords in the MHSA that need referencing. This type of question is referred to as its ‘format’ in this paper, and the format indicates how the question is phrased. An example is as follows:

- Q1. 'Can an employer allow a minor to work underground?'
- Q2. 'Can an employer allow a juvenile to work underground?'

The two questions are the same; but the difference is that in Q1, the word 'minor' is descriptive while 'juvenile' is a keyword from the MHSA law book. Therefore, how the candidate would answer the questions is not the same. In Q1, the descriptive question, the candidate would need to know that 'minor' is synonymous with 'juvenile' so that they can find a relevant answer in the law book. With Q2, which is a keyword-based question, the candidate can go straight to the book to find the answer. The distinction of the question type/ format is illustrated in Figure 2 and is discussed further below.

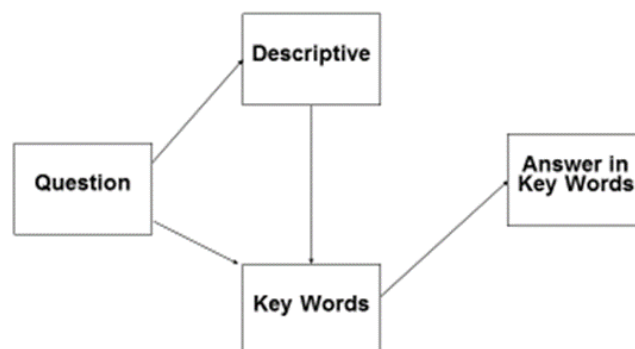


Figure 2. Flow chart of how candidates can approach answering questions in the examination.

The type/format of the questions were broken into two categories – namely descriptive and keyword based. Descriptive questions describe a mining scenario without quoting keywords from the applicable legislation. Words or phrases that match with or can be paired with keywords in the book are descriptive words; an example is ‘decline’ instead of ‘incline’ and ‘minor’ instead of ‘juvenile’. By contrast, ‘incline’ and ‘juvenile’ are keywords because they appear in the MHSA law book. An example of a descriptive question could be: ‘List safe devices in a decline shaft.’ The word ‘decline’ does not appear in the MHSA book. The candidate has to convert it to ‘incline’, which is in the book, in order to locate a reference for the answer in the MSHA book. Figure 2 shows the flow chart for both types/format of questions to get to the answer.

Our analysis of the 2010-2019 examination papers indicated that 63% of the questions were descriptive and 37% were keyword-based. Figure 3 presents the percentages for the two question formats as observed from the 2010-2019 examination papers.

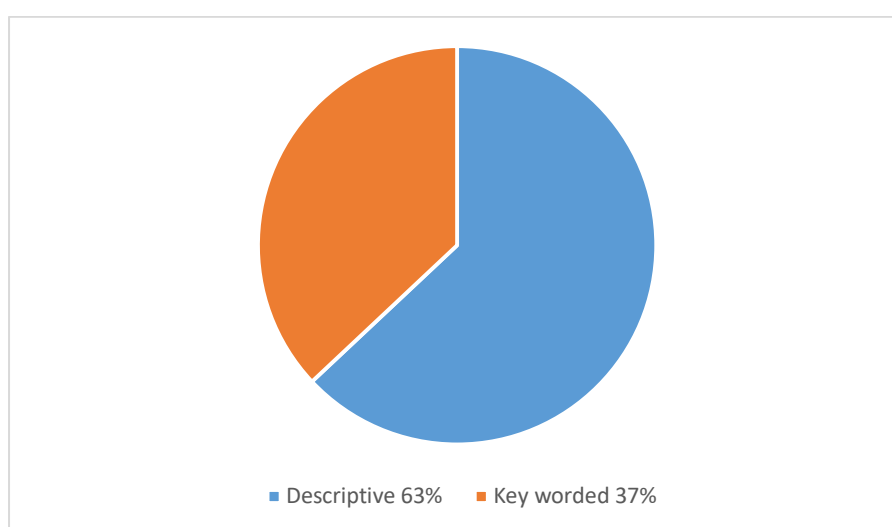


Figure 3. Percentages for each question format.

It is important to understand the format of a question so that the candidate knows how to answer it. For example, keyword questions require answers in the form of keywords. For descriptive questions, the candidate must first convert the descriptive words to keywords and then find the answer in the law book, in the form of those keywords. There are thus two challenges with descriptive questions: first the candidate must identify which word or phrase in the question is descriptive; then they must translate that descriptive word or phrase into a keyword(s) similar to what is in the MHSA law book. Only then can the candidate find the required reference in the law book (the examination is open book).

Figure 4 shows the percentage distribution of question themes. The question themes were 64% issue-specific, 24% health-, 6% procedure-, 3% other-, 1% check-, 1% issue – other-, and 1% new / change.

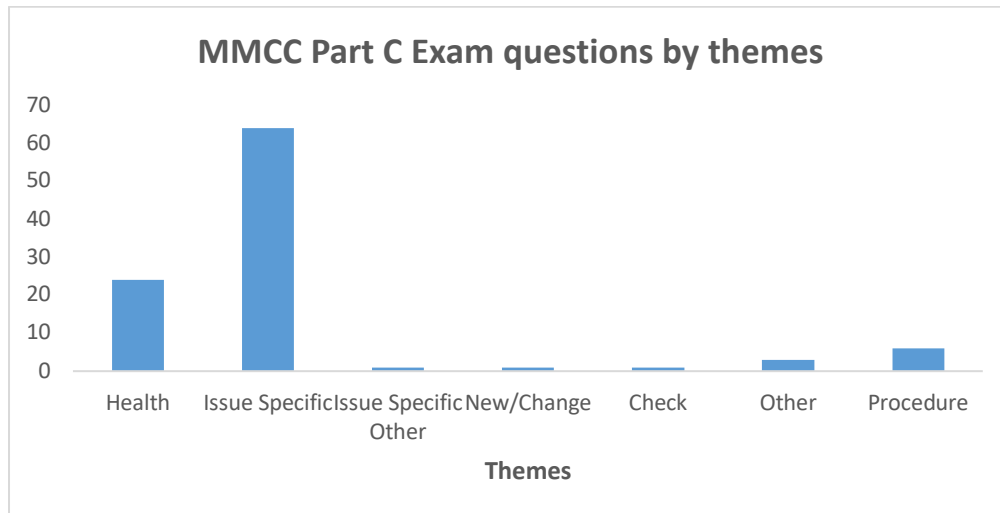


Figure 4. Percentage of questions' themes.

The question theme definitions are provided below as follows:

- a) **Issue – Specific:** These questions probe what must be complied with in the Act, regulations, or any legal documents. The MHSA is a risk management document that outlines issue-specific mining operations, Acts, or practices that require compliance. An example is as follows: *'List any five relevant regulations of the Act relating to the payment of levies by mines'* (MMCC Part C Examination, May 2011, Q5).
- b) **Health:** These questions fall into two categories: occupational hygiene and occupational health. Examples are questions on medical surveillance systems, procedure, health records, and health hazards. An example of a health question is: *'List any ten relevant sections or regulations of the Act that govern the health of persons at a mine'* (MMCC Part C Examination, October 2018, Q4.1).
- c) **Procedure:** These questions relate to instances where significant risk has been identified for certain work. Hence, to execute such work, chronological steps or a flow chart can be followed. For example, *'Employees under your charge complain about some supervisors forcing them to work in areas that are dangerous. On scrutinising the health and safety induction training material at the mine you realise that employees were only trained on the extract of Section 23(2) of the Act. You want to solve this complaint to restore confidence in your employees. Draw a flow diagram indicating how you would ensure that the procedure required in terms of the Act becomes more effective.'* (MMCC Part C Examination, October 2014, Q4.1).
- d) **Other:** These are opinion questions or calculations, or information from the syllabus. For example, *'Unfortunately, the 2003 milestone commitments on noise were not met in 2013. In your opinion, what are the reasons for failing to achieve the aforesaid commitments and which strategies should be implemented to ensure achievement of the new milestone commitments?'* (MMCC Examination, October 2015, Q2.2).'
- e) **Check:** These questions pertain to where compliance has failed, or the issue-specific requirements have proven inadequate to prevent an accident or unwanted outcome. For example: *'The prevalence of fire accidents in South African underground mines is disturbing. In the recent past, mine fire accidents have unfortunately been reported at Impala 14 Shaft in January 2016, Kusasaletu Gold Mine in October 2014 and February 2015, Doornkop Gold Mine in February 2014, Driefontein Gold Mine in June 2012 and Phakisa Gold Mine in June 2010. In light of the aforesaid, which provisions of the Act, excluding those covered in Chapter 16 dealing with first aid and rescue brigades, which if adhered to, could have prevented these unfortunate accidents?'* (MMCC Part C Examination, October 2016, Q5).
- f) **Issue – Other:** This is a question that the candidate is supposed to answer without giving the obvious issue-specific answers. For example, in a question relating to fall of ground, the examiner knows that Chapter 14 of the MHSA regulations is issue-specific regarding prevention of falls of ground. Nonetheless, the examiner specifically instructs the candidate to answer the question without referring to Chapter 14. An example is as follows: *'List twenty relevant sections or regulations*

- of the Act, excluding regulations mentioned under Chapter 14 of the Act, which if adhered to will assist in eliminating fall of ground (FOG) fatalities’ (MMCC Part C Examination, May 2016, Q1).
- g) New / Change: These questions relate to a routine operation that has to be changed because a need has arisen to undertake new work or to conduct the work differently. An example is the need to break rocks with an alternative method. For example, ‘Due to sudden extra coal production demands, you are required to open up a new drill and blast section in your fiery mine which is currently using mechanical miners only. What are the main regulations or sections of the Act which must be addressed?’ (MMCC Part C Examination, May 2011, Q7).

Figure 5 shows the percentage distribution of information sources – that is subject area sources for obtaining the answers. Two sources require brief definition. ‘Outsource’ refers to answers that are not found in the MHSA book but are found in repealed legislation, mining houses’ drawn procedures, flow charts from the Chief Inspector of Mines mandatory codes of practice, mining summit milestones, and unit standards (for blasting certificate training). ‘Other’ refers to answers requiring the candidate’s opinion or an answer for a question that is not in the syllabus.

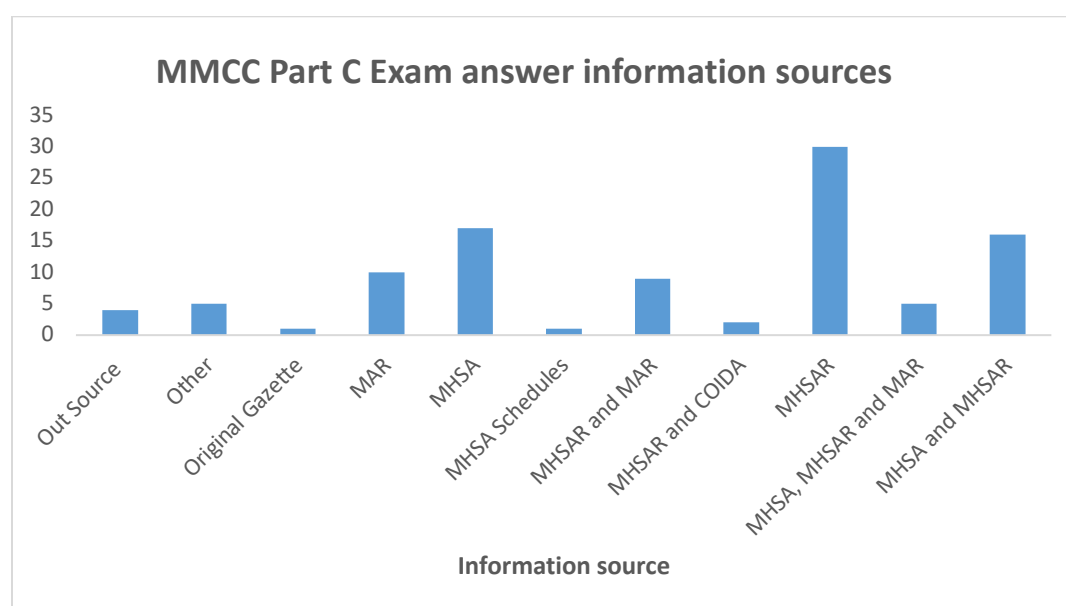


Figure 5. Percentage distribution of information sources.

The analysis yielded the following results: the information sources span from 30% Mine Health and Safety Act and Regulations (MHSAR) document ; 17% MHSA Sections; 16% MHSA Sections and MHSAR; 10% Minerals Act Regulations (MAR); 9% MHSAR and MAR; 5% MHSA Sections, MHSAR and MAR; 5% other; 4% outsource; 2% MHSAR and Compensation For Occupational Injuries And Diseases Act, No 130 Of 1993 (COIDA); 1% Original Gazette of the MHSA Sections; 1% MHSA Schedules.

DISCUSSIONS

Of all the examination questions we analysed, 64% required specific answers from the MHSA book. This finding makes sense because the MHSA is a risk management document that is meant to eliminate, control, or minimise risk. Hence, testing the candidate’s ability to identify the best risk management controls (issue-specific answer) is critical to test their knowledge and competence. The percentage of questions relating to health issues was 25%, and questions focused on work procedures were 6%. A candidate who is weak on issue-specific concepts of the MHSA would likely fail this type of examination.

For issue-specific questions, we noted that there were two or more aspects that a candidate must be

aware of, namely, the 'preventative' and 'mitigation' concepts of the MHSA. An example to distinguish between 'preventative' and 'mitigation' is a question that is silent on which one is preferable; the best answer would be 'preventative'. For example, the question can state *'List one report that you find in the MHSA'*. The best answer is a routine report rather than a report because an incident has likely happened. An example question about reports pertaining to an incident that has happened is *'What are the associated statutory reporting forms for exposure to airborne pollutants, thermal stress, and noise?'* (MMCC Part C Examination, May 2012, Q1.2).

We were unable to establish a trend over the ten-year period as very few questions were repeated. However, it seems some questions have been repeated based on concerns in the mining industry during a specific year in terms of health and safety. This means that candidates preparing for the MMCC examination must keep abreast of major health and safety incidents or accidents happening both in South Africa and globally. Between 2010-2019 the MMCC Part C examination, questions relating to health have played a significant role in acquiring a pass mark. These health questions had to do with the following topics: occupational health hazards; medical surveillance records; medical surveillance systems; noise-induced hearing loss; health matters; occupational exposure limit; procedure to determine levels of exposure to hazardous substances at the mine; occupational diseases; mining summit milestones are also a source for 'other'.

Compliance (issue-specific) requires identifying sections or regulations of the MHSA or any prescribed document that are issue-specific to an operation or Act. An example is mining summit milestones and the Mandatory Codes of Practice of the MHSA. Between 2010-2019, answers required from candidates could be categorised as 'direct', 'semi-direct' and 'generic', or a combination of the three depending on the question.

To examine the above categories more closely, we coded a direct answer as A, a semi-direct answer as B, and generic answers as C. An incorrect answer would be D. An issue-specific answer could be classified in the following categories with respect to the accuracy of details: A is always correct; B is correct only if there are no As; C is correct only if there are no As or Bs and Ds are always incorrect. It is crucial for MMCC Part C coaches and candidates to be well versed in providing A answers. To illustrate a category A answer, the following question is instructive: *'During a safety review with your Mine Overseers following a blast related incident in one of your shafts, you noticed that not all of the Mine Overseers were aware of the regulations relating to explosives. You are then given an instruction as the manager that all the Mine Overseers must prepare a presentation for Shift bosses and Miners, covering all the aspects of these regulations. What is the purpose of each written procedure required under the regulations on explosives?'* (MMCC Part C Examination, May 2018, Q5).

A category A answer in this case must be based on the regulations relating to explosives. Furthermore, it should contain the words 'written procedure'. Hence, if the answer is based on the same regulations but only contains the word 'procedure', it would fall under category B.

Repeat Questions

The questions that were set more than once appeared at most three times within the ten-year period, constituting 6% of all the questions we analysed. We formulated a tentative hypothesis that examiners may repeat questions that have been poorly answered in previous examinations. Further research would be required to investigate this hypothesis. The subject matter in the repeated questions consisted of the following topics:

- Purpose of each written procedure in the explosives' regulations
- Examination of winders in shafts
- Approvals by the Principal Inspector of Mines
- Warning systems in shafts
- Flammable gas accidents at mines
- Use of self-contained self-rescuers
- COP guidelines issued by the Chief Inspector of Mines
- Collection of Council levies

- Safety issues for communities due to blasting operations
- Emergency preparedness – such as after an underground fire, massive falls of ground, and a methane or coal dust explosion
- Mine occupational health diseases
- Requirements regarding winding ropes being cut or installed
- Material handling in shafts
- Mine Health and Safety Tripartite Summit milestones
- Medical surveillance systems for employees exposed to hazardous substances
- Procedure to determine levels of exposure to hazardous substances at the mine
- Duties and responsibilities of legally appointed persons
- Health and safety of non-mine employees
- Identifying safety devices in shafts
- Requirements for the use of chairlifts

Most questions were not repeated, and it was uncommon for a question to be repeated in consecutive years. Over the study period 2010-2019, repeated questions were observed only in the October 2017 and May 2018 examinations. The question stated, *‘List any six relevant sections or regulations of the Act that refer to a procedure that must be followed by the employer to determine levels of exposure to health hazards at the mine’* (MMCC Examination Part C October 2017, Q1.3 and May 2018, Q2.3).

We assumed that a question is repeated for two reasons. The first is poor performance by candidates on that specific question; and the second is to reinforce or highlight a recurring problem in mine operations.

CONCLUSIONS

Failure by candidates to pass the MMCC Part C examination could largely be the result of candidates not being well versed in the importance of issue-specific answers, A answers, and health-related topics. If that is the case for the failure rate, it means that compliance with the MHSA in practice is not well understood by some candidates sitting the examinations. A possible reason could be that some candidates take the MMCC Part C examination prematurely, before they are fully prepared with adequate practical mining experience (above 5 years) in the area of health and safety. This reasoning is congruent with our earlier findings (Ndiweni & Mpanza 2018) that some candidates sat the examination within five years after joining the mining industry.

The MMCC Part C examinations are internationally competitive. However, the instructions provided in the examination papers may appear misleading to candidates, as they do not clarify how the candidates should satisfactorily demonstrate their knowledge and competency.

These research findings should assist not only MMCC Part C examination candidates but also the coaches or mentors who help to prepare such candidates. Mentors should examine the candidates on key issues in the MHSA and other source documents. The list of subject areas given above should help to achieve an improved pass rate, compared with the poor results we reported in our previous study.

RECOMMENDATIONS

Correct preparation for the MMCC Part C open-book examination requires that candidates index or tag pages in the MHSA book. This indexing or tagging can be done electronically or physically. This paper identifies important categories for candidates to focus on, and to index or tag, when preparing for the MMCC Part C examination. The key subject areas are as follows:

Administrative fines, annual reports, appeals, appointments, blasting certificate, boilers, chairlifts, communication systems, code of practice (COP), definitions, draw points, duties and responsibilities, emergency preparedness, exemption, explosions, explosives, fall of ground, fiery mines, fires, flammable gas, MHSA Chapter 21, gas explosion, hazardous location, hazardous substances, health,

health and safety committees, health and safety representatives, health records, hours of work, inundation, ISO standards, levies, material handling in shafts, medical surveillance records, medical surveillance systems, mine closure, mine rescue service provider, mine rescue teams, mine ventilation and rescue plans, mining summit milestones, mono rope winches, noise induced hearing loss (NIHL), non-mine employees, objects of the MHSA, occupational diseases, occupational hazards, occupational exposure limit (OEL), offences, principal inspector of mines (PIOM) approvals, PIOM permissions, portable water, procedures, prohibitions, qualifications, records, refrigeration plant, reports, representative trade union, rights, risk assessment, SABS, safety devices, SANS codes, self-contained self-rescuer (SCSR), shaft examination, shafts, standards, Sunday labour, surveying, trackless mobile machinery, warning systems, water pollution, winders, winding rope, and written procedures (MHSA, 1996).

These key subject areas can be used by candidates as a learner guide when searching for subjects in the MHSA law book that need to be read thoroughly. Such study should occur before attempting to complete past question papers as part of examination preparation.

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Ntabiso Ndiweni

Mining Engineering Lecturer
University of Johannesburg

- 35 years of mining experience
- DMRE Principal Inspector of Mines (1997 to 2004)
- Mining Department Lecturer at UJ (2005 to date)
- Mining Industry MHSA-related training (2005 to date)
- MMCC Part C Coaching (2005 to date)
- Auditing systems on SOPs, training and competence management

Leveraging digital twins and virtual reality in mining incident investigations: Unlocking the 'Black Box' of incident data

J. van Dalen and H. Dippenaar

Dayenu Mining Consultants, South Africa

In the context of achieving a 'Zero Harm' status in the South African mining industry, we need to unlock the 'black box' of data on the incidents and accidents that stand between the Zero Harm status and the 1907 serious injuries reported in 2023. The utilisation of digital twin and virtual reality (VR) technologies enables us to take a transformative leap from traditional investigation methods. This new methodology has the potential to gain new insights and identify new opportunities to transform incident investigations and enhance the value that such an incident investigation adds to the overall investigative processes.

My work has been dedicated to the development and testing of new methodologies that harness the power of digital twins, VR, and the use of robotics to access areas that have been off-limits until now. These cutting-edge technologies offer the potential to overcome the conventional limitations of incident analysis. By accessing areas that have been off-limits due to dangerous conditions, we can now access the black box data of an incident scene, such as a fall of ground, through remotely operated vehicles. The black box data can be reconstructed, and critical spatial data can be extracted: for example, the angle and spacing of permanent support in an area that experienced a fall of ground incident. The digital twin and VR environment enables investigators to access the scene of the incident without the risks associated with an underground investigation.

The data is not only limited to spatial data but also includes visual data, allowing us to see where it was never possible to see before. This approach empowers us to visualise and analyse intricate sequences of events through a digital reconstruction of the incident scene, as well as the timestamp data that might be available in the vicinity of the incident. This could assist in determining the root cause of an incident and make better recommendations to prevent recurrences. The conference's objectives align closely with the research, which aims to identify a methodology that can save lives, reduce incidents, and enhance the learning from incident process to add value towards achieving a Zero Harm state in the South African mining industry.

BACKGROUND AND PROBLEM STATEMENT

In 2023, the South African mining industry employed 477,000 people, while contributing more than R450 billion to the GDP. It was one of two formal non-agricultural industries that employed more people since Q4 of 2019 compared to finance, electricity and water, manufacturing, internal trade, transport, and construction which were significantly lower compared to Q4 of 2019 (between 4% and 18% fewer jobs) (MCSA, 2024). The country's progression has been supported by job creation and the sale of commodities on the international market (Lane *et al.*, 2015). Lane *et al.*, (2015) explain that mining companies are constantly confronted with higher costs, which reduces profitability in the search for commodities as they go deeper.

Furthermore, the danger of mining at deeper levels increases risks (such as ventilation constraints, fall of grounds (FOG), flooding, and seismicity), posing direct threats to the safety of the mining employees. The mining industry recorded 55 fatalities in 2023 and 1907 reportable injuries for the same period (03, 2024). It must be admitted that the mining industry has come a long way since the nineties when it was reported that 735 deaths (0.99 death rate) and 10 097 injuries (13.63 Injury rate) occurred in South African mines in 1989 (115, 1991). Regrettably, the mining industry is yet to achieve a state of 'Zero-Harm' (Johnson, 2018; Jusko, 2019; Adams, 2011). Given the prevailing mining incidents and accidents, the crucial need for to improve the understanding of the black box' data of an investigation remains an undeniable reality to effectively mitigate the recurrence and ultimately achieve a state of Zero Harm.

Objectives and Scope

The potential benefits of utilising a combination of available technologies such as virtual reality (VR), digital twins, remotely operated vehicles (ROVs), and the field of gaming engineering to enhance the safety and efficiency of incident investigation processes are discussed in this paper. In the South African context, the potential risks we face as we mine deeper than ever before pose a serious challenge due to the increasing complexity of targeted mineral deposits (relating to depth, structure, and geotechnical issues) makes mining less 'standard' when an investigation is conducted after the occurrence of an incident or accident. The authors argue that the highlighted technology, with accompanying potential solutions, could enhance incident investigations and progress toward prediction and prevention by identifying potential hazards and improving the efficiency and effectiveness of incident investigations.

VIRTUAL REALITY SOLUTIONS

Introduction to VR Technology

VR relates to three-dimensional, virtual environments that have been computer-generated (Hamad and Jia, 2022). VR can be categorised into two main categories, namely: Immersive and non-immersive (Wohlgenannt, 2020). Immersive VR will make use of a wearable display and allow the user to experience 360° of the virtual environment (Hamad and Jia, 2022). Non-immersive VR will make use of screens to display the virtual environment (Rahouti *et al.*, 2021).

VR has successfully been utilised in a deep-level mine in South Africa, to capture an accident scene as part of an investigation (Grobler *et al.*, 2021). By doing so, the author gained access to a digital twin of the underground environment, creating an exact replica of the surroundings in a virtual setting. This innovative approach allowed the author to navigate and explore the accident scene without being exposed to the actual risks present in that specific area.

Through the VR platform, the author could freely move around, make observations, and mark positions of interest. These critical findings could then be shared with authorised personnel who could access the VR scene through desktop computers or mobile devices. The VR experience offered two options: an immersive setting, where users feel fully present within the virtual environment, and a non-immersive setting, where users interact with the virtual data on a screen.

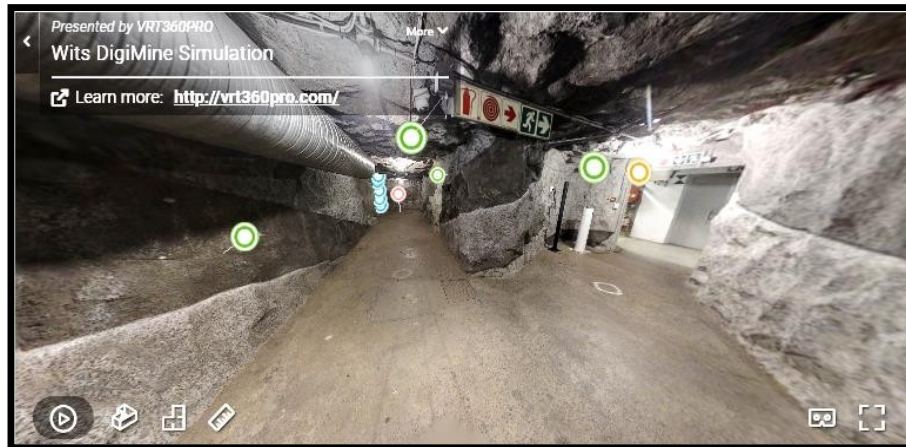


Figure 1. Proof of concept in a simulated mine (University of Witwatersrand)



Figure 2. Underground VR environment of a tunnel bore

Employing VR technology in this manner proved that VR is a valuable tool to enhance safety and efficiency during an incident investigation, as it allowed personnel to thoroughly analyse scenes, gather information, and communicate findings without compromising their well-being in the actual hazardous environment.

Applications in Incident Investigations

The VR environment can serve as a digital replica of the investigation scene, providing an immersive and accurate representation for investigative purposes. This could allow for the preservation of the incident scene which can be used to help to identify strategic factors such as physical hazards, location and positioning, accessibility of the space, exposure risk, construction, and contents of the scene of the incident (Browne and Crist, 2010).

Using VR to inform and update the extended investigation team, who may not have been part of the underground visit, can be crucial. By immersing the team in a virtual recreation of the underground environment, they can gain a better understanding of the site and its potential risks. This allows them to contribute more effectively to the investigation and aids in the generation of well-informed action plans. The recorded VR environments can serve as valuable training material for mining personnel, enabling them to simulate and prepare for various risks identified in the mining operations. This can greatly aid in computer-based training and enhance the overall safety and preparedness of the personnel. The advantage of using VR as a training tool lies in its ability to provide repeatable and

flexible procedures within a secure environment (Xu and Zheng, 2021). Xu and Zheng (2021) further elaborate on a comparative evaluation that was conducted – comparing traditional methods with the proposed VR solution. The results showed that workers were better trained in an immersive VR environment, as they could memorise critical points more effectively. The implementation of VR technology enables individuals to experience hazardous situations without physical harm, creating a safer and more efficient training environment.

Benefits and Challenges

A primary benefit of using VR during an investigation is that it presents the audience with a digital twin of the environment, with a high level of detail. The technology of reality-capture has advanced over the last few years, and a mobile device such as the i-Phone has made it possible to scan areas and map sites to produce three-dimensional point clouds of the mining area (Birch and Olivier, 2022). Such a device could allow for immediate surveying and mapping of an incident scene if employed by the initial response team. Such a preliminary view of the incident assists investigators in forming a better impression of the scene and surroundings. Figure 3 illustrates the scan that has been rendered in third-party software, providing valuable data for the investigation.



Figure 3. An underground i-Phone scan 3D model of a haulage with tracks

A secondary benefit of using VR technologies is that it facilitates an immersive training experience that is based on real or simulated incidents or accidents. This method of training is particularly useful for new or less experienced members involved in incident investigations at the mine.

Challenges related to capturing a VR environment for incident investigations are indeed noteworthy. One of the primary challenges is ensuring sufficient illumination of surfaces during the scanning process. Inadequate lighting can lead to inaccuracies and distortions in the final product, affecting the usability of the captured data (Grobler *et al.*, 2021).

Additionally, the size of the area being scanned presents a significant challenge. Larger areas require more time for processing, potentially causing delays in accessing the VR environment. The processing power of the device (used for capturing and rendering the VR content) also plays a crucial role in determining the speed and efficiency of this process.

Overall, overcoming these challenges is essential to leverage VR technology effectively during investigations. Improved scanning techniques, advanced processing capabilities, and careful planning

for capturing VR environments can help enhance the utility and applicability of VR solutions in investigation scenarios.

REMOTELY OPERATED VEHICLES AND INVESTIGATIONS

The effectiveness of a successful investigation is much like a mine rescue operation that largely depends on three critical elements: Special people, special equipment, and special training (Martinette and Zawlocki, 2006). The special people involved in incident investigations require state of the art equipment to ensure safety and effectiveness during investigations. Innovations need to help address the major challenges that the mining industry is facing, such as stricter legislation concerning the health and safety of workers, the community, the environment, and infrastructure.

Types of ROVs

ROVs can be classified based on their size, capabilities, and intended use. Multiple ROVs are available for evaluation in the South African context. Rubio *et al.*, (2019) describes the common types of ROVs used in reconnaissance, segregating land-based from air-based options.

Land-based

Wheeled mobile robot

This ROV (illustrated in Figure 4) utilises wheels as its primary mode of locomotion. Motorised wheels enable the wheeled mobile robot (WMR) to navigate over various types of terrain, including uneven and rough surfaces. Wheels, rather than treads or legs, provide a simpler alternative in terms of design, construction, and programming (Rubio *et al.*, 2019).



Figure 4. The WMR (Tóth *et al.*, 2015). A remotely operated vehicle (a land-based option) for consideration in the pursuit of optimising incident investigations in the context of South Africa

Walking (or legged) mobile robot

A walking mobile robot is equipped with legs that can push against a surface for propulsion in a specified direction (Carpentier and Wieber, 2021). Legged robots demonstrate remarkable versatility and possess the capability of navigating intricate and confined spaces with ease (Buchanan *et al.*, 2020).

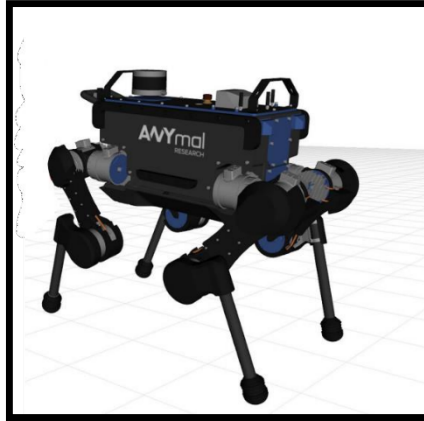


Figure 5. The walking /legged mobile robot (Buchanan et al., 2020), under investigation for use in mine rescue operations

Tracked slip/skid locomotion

The robot displayed in Figure 6 is fitted with wheels, powered by motors, and (in turn) drives the tracks of the vehicle (Wang et al., 2022). However, Wang et al., (2022) explain that track robots are vulnerable to skidding and slipping – which may complicate control over the robot.



Figure 6. An example of a track robot (Wang et al., 2022)

Hybrid

A hybrid robot can be defined as a robotic system that incorporates diverse locomotion systems, while combining different methods of movement (Kashiri et al., 2019).



Figure 7. An example of a hybrid robot – a wheel-legged robot (Kashiri et al., 2019)

Air-based

Air-based robots, also known as unmanned aerial vehicles, can be categorised based on their weight size, and various other structural characteristics (Luthra, 2023).



Figure 8. An example of a drone, capable of being manipulated within tight spaces (autonomousaerialrobot.com)

Applications in Mine Incident Investigations

During a mine incident investigation, the team encounters various challenges and hazards (Reddy *et al.*, 2015). Reddy *et al.* (2015) demarcates risks – such as fall of ground (FOG), and conditions of low visibility. Considering the time sensitivity to initiate an investigation, alongside a paramount concern for the safety of the team conducting the investigation, the deployment of robots (Zhai *et al.*, 2020) could facilitate the safety of the investigation teams by reducing the risk of secondary disasters while searching for critical information. The robot system is specifically engineered to remotely observe and gather information during rescue operations (Zhao *et al.*, 2017). This can be a critical tool to assist mine rescue teams to capture critical information when responding to an accident scene and simultaneously capture critical information that can assist in mission success but can also be used for incident investigations.

Search and Rescue Missions

Jorge *et al.*, (2019) advocates for the potential significance of disaster robots, with the entailing statement, “In areas affected by disasters, the safety of rescue teams can be compromised.” Such situations exemplify how robots can play a pivotal role in ensuring the safety of the rescue team. The proposed use of ROVs (equipped with sensors, high-definition cameras, and LiDAR technologies) should enable the capturing of detailed spatial data at the site of an incident (in both surface and underground mining environments). The capabilities of this equipment and the data provided by them can be used for immediate response and to assist in ongoing rescue operations.

Reconnaissance and Assessment

Blindly entering an accident scene frequently poses life-threatening risks to rescuers (Li *et al.*, 2019). During the evacuation and rescue stages, it is crucial to conduct thorough assessments to save lives and minimise asset damage effectively (Jorge *et al.*, 2019). The implementation of robots equipped with a range of real-time monitoring sensors can greatly enhance the situation. These sensors, which include those for measuring temperature, radiation, pressure, airflow, distance, gas detection, imaging, and sound, offer valuable data that can inform rescue efforts (Dunbabin and Marques, 2012).

Furthermore, the integration of ROV and LiDAR equipment can significantly aid in reconnaissance and evaluating conditions in hazardous and non-permissive environments (Li *et al.*, 2022). This technology could allow the rescue team and control room to obtain real-time information about the site's physical conditions and the potential status of patients. The data captured during these reconnaissance missions is not only crucial for immediate rescue operations but also serves as a critical resource for subsequent investigations. Since this information represents the incident's conditions as close to the event as possible, it can provide invaluable insights (Jorge *et al.*, 2019). However, it is important to recognise that the scene may change due to rescue operations or the deterioration of conditions over time. This emphasises the importance of accurate and timely data collection to ensure that both rescue efforts and future investigations are based on the most reliable information available.

Remote Data Collection

In incident investigations, the implementation of ROVs with autonomous exploration and mapping capabilities has revolutionised the process of remote data collection, proving to be a crucial asset for the overall success of the investigation. The 'Groundhog' robot, equipped with autonomous features, has been instrumental in gathering critical data (Moczulski *et al.*, 2015). By deploying these advanced robots, investigation team members can now be further away from the scene of the incident or accident, while the ROVs efficiently map the area (Jorge *et al.*, 2019). The use of ROVs in place of human involvement addresses various hazardous situations such as mechanical, environmental, electrical, and chemical risks, as well as potential inrush of fluid materials (gas, mud, and water), and engulfment hazards (Spurlock, 2017). It also eliminates the need for human entry into areas vulnerable to soil collapse and entrapment; ensuring the safety of investigation teams (Martinette and Zawlocki, 2006; Johnson and Fourie, 2023) without compromising the quality of critical data. As a result, remote data collection, through ROVs, could significantly improve the efficiency, quality, and safety of incident investigations.

Victim Retrieval During Mine Rescue Operations

Failure to promptly respond to disasters and efficiently rescue survivors can result in prolonged suffering and loss of life (Jorge *et al.*, 2019). ROVs, equipped with specialised sensors, can automatically detect and identify victims in cluttered environments. By capturing 2D and 3D images of the scene, the ROVs can detect possible victims, even if they are only partially exposed (Louie and Nejat, 2013). This method proves effective in determining the presence of victims during search and rescue operations. The ROVs' ability to be used as modes of transportation could be leveraged to deliver much needed aid to victims who can't be reached by the rescue teams, including, first aid, oxygen, water (Chitikena *et al.*, 2023), tools and materials. ROVs like 'Rex' have the capability to transport victims or equipment over significant distances, with a maximum load capacity of 227 kg (Martinic, 2014).

Advantages and Limitations

Advantages of ROVs

Utilising ROVs translates to having updated spatial, visual, and other sensor data available – this offers several significant advantages in informing the investigation at hand:

- I. **Enhanced Access to Information:** Robots can access areas that have been deemed off-limits for the investigation team to the potential risks identified; risk of injury can be reduced without compromising the quality of the data (Trevelyan *et al.*, 2008).
- II. **Identification of Evidence:** ROVs equipped with specialised sensors can aid in the identification of evidence (Louie and Nejat, 2013; Johnson and Fourie, 2023) and streamline the investigation.
- III. **Real-time Environmental Hazard Information:** Access to real-time data on environmental hazards (such as unstable rocks, unsupported areas, barricades, and rising water due to FOG), provides crucial insights for conducting safe and effective investigations. This information can help (Hudson, 1988) investigation teams monitor and record real-time data that could add value to understanding the root cause of the incident.
- IV. **Data-driven Decision Making:** By providing updated and detailed information, ROVs assist in forming a better understanding (Browne and Crist, 2010) of the incident allowing improved risk assessment and a better understanding of the unwanted event being investigated.
- V. **Informing Operational Strategies:** Providing detailed spatial and structural information can aid mining teams in developing a safe and effective strategy for addressing FOG or repairing infrastructure compromised by accidents or incidents. Moreover, it could help determine requirements and select appropriate equipment. Understanding the unique environmental factors (Hudson, 1988) of the incident area, enabled by near real-time mapping through ROVs, is crucial in tailoring repairs and rehabilitation strategies effectively.

ROVs can significantly impact emergency management in four key areas: mitigation, preparedness, response, and recovery (Chitikena *et al.*, 2023). They enable safe and effective information gathering during emergencies and facilitate investigation processes. With access to critical insights, the investigation team can make informed decisions, ultimately enhancing the overall efficiency and success of the investigation.

Limitations of ROVs

ROVs, while valuable tools during reconnaissance, also come with several limitations that need to be considered:

- I. **Space Limitations:** ROVs may face constraints in navigating through tight or confined spaces within the mine environment, potentially limiting their accessibility to certain areas (Zhai *et al.*, 2020).
- II. **Weight and Transportation:** Many existing robots that could be used for rescue operations are heavy and not easily transportable or deployable, which could hinder their quick and efficient deployment during emergencies. Additionally, maintaining reliable communication between the ROV and the base station could be challenging – especially in unstructured and constantly changing environments (Reddy *et al.*, 2015), inherent to a rescue operation.
- III. **Intrinsically Safe Sensors:** Ensuring that the ROV's sensors are intrinsically safe (Zhao *et al.*, 2017) poses a significant challenge, due to the possibility of encountering flammable gases, which could pose a significant risk to the persons involved in the investigation or rescue operation.
- IV. **Environmental Limitations:** ROVs may face difficulties when operating in harsh conditions within the mine, such as dealing with dirt, water, confined spaces, uneven surfaces, and various obstacles (Chitikena *et al.*, 2023). These factors can affect the effectiveness and maneuverability of ROVs.
- V. **Vision Sensor Limitations:** The effectiveness of vision sensors used in ROVs can be impacted by various factors, such as low visibility conditions or limited visual cues (Tóth *et al.*, 2015), which may affect their ability to accurately perceive and navigate the environment.

While ROVs offer significant benefits in reconnaissance, it is essential to be aware of their limitations. Addressing these challenges through ongoing research and technological advancements can lead to more effective and reliable ROV systems in the future.

INCIDENT RECONSTRUCTION AND DATA DRIVEN SIMULATIONS

To better understand the events that led to the unwanted occurrence, the combination of spatial and visual data can be utilised as a digital representation in the form of a digital twin. This approach allows for accurate simulations and reconstruction strategies. Timestamp data serves as a key factor driving the movements within the simulation models. This methodology facilitates the development and testing of hypotheses in a digital environment that is an exact replica of the physical scene where the unwanted event took place.

Reconstruction of an Incident or Accident

The following case study is based on a fatal shooting. The investigators needed to establish whether the shooting was an accident or homicide (Buck, *et al.*, 2013). During an argument, a young man fired a shot from his firearm and fatally wounded his father. The young man testified that they argued in a bedroom when his father shoved him. According to the accused and only witness, he fell backwards and accidentally fired a shot, wounding his father in the abdomen. The only evidence that was available for the investigating team was the statement of the accused, the bullet wound of the deceased, the suspended round, the firearm, and the scene where the shooting occurred (Buck, *et al.*, 2013).

The district attorney ordered that the scene of the shooting be scanned and reconstructed as a 3D virtual environment. The investigators used a Faro 3D scanner to capture this environment and with the 3D models it was possible to reconstruct the scene according to the accused.

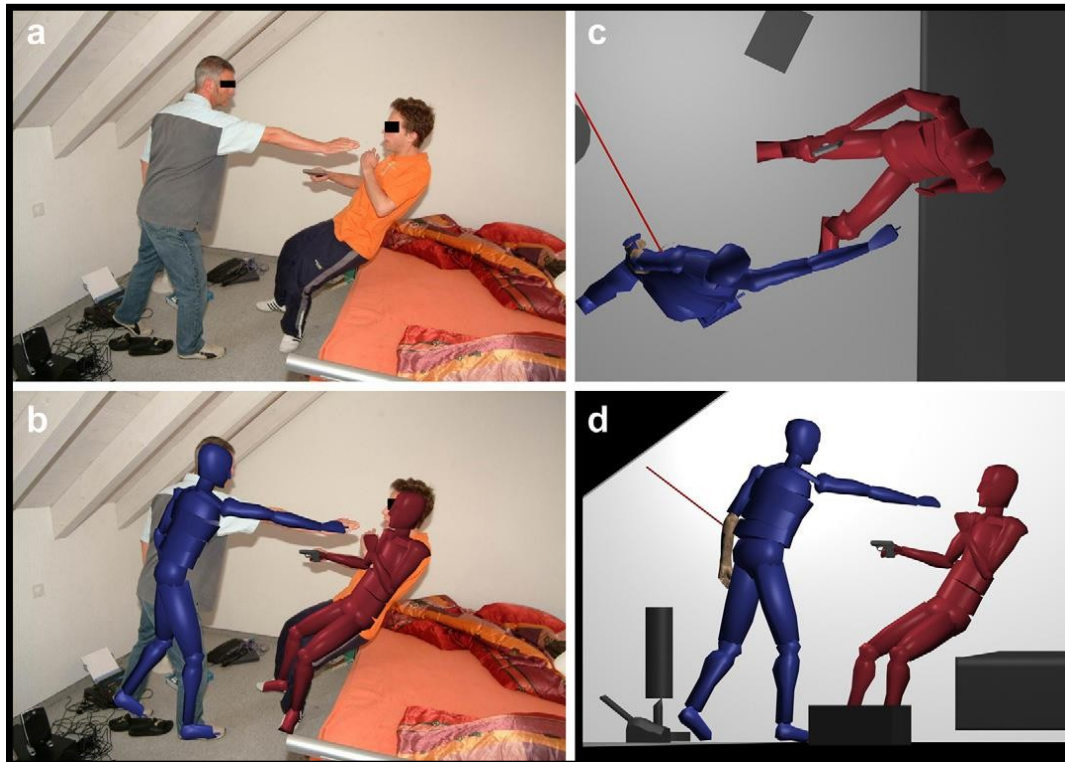


Figure 9. Reconstruction process (Buck, *et al.*, 2013)

a) Investigators simulate the witness report. b) 3D modelling based on the accepted simulation. c) Top view of the 3D models representing the deceased and the accused. d) Side view of the 3D models representing the deceased and the accused.

The investigators were able to combine the medical data with the 3D models to establish a trajectory of the bullet and reconstruct it into the virtual 3D environment. All possible trajectories were reconstructed from the witness report, which failed to match the medical evidence that proved that the trajectory did not match the witness version of the event.

This is an example of how technology can be used to distinguish between fact and fiction. In this case, it was the difference between the verdict of an accident and a homicide. The results of this specific methodology can have far-reaching consequences. The evidence proved that someone did indeed commit a murder, but the same methodology could equally be used to prove if someone was innocent (Buck, *et al.*, 2013).

Currently, mine surveyors in South African mines are increasingly making use of 3D scanners to record significant injuries and fatality scenes (Webber-Youngman, *et al.*, 2019). Unfortunately, this has not yet replaced the traditional way of investigating. The literature proves that the South African mining industry is going in the right direction to improve the quality of accident and fatality investigations. 3D scans provide a point-cloud with large amounts of data, significantly much more than traditional 2D plans and photographs. Webber-Youngman, *et al.*, (2019) identified shortfalls of traditional 2D plans and methods:

- Tacheometry, tape surveys, and photographs are tedious to use;
 - The recording of data is dependent on perspective and interpretation;
 - Recorded data can be manipulated;
 - Erroneous recordings and measurements will result in errors in interpretation;
 - Section view drawings do not present sufficient detail of the reconstructed environment;
- and

- Important evidence can be missed.

A critical shortfall of traditional 2D plans and methods would be important evidence missed or overlooked during the investigation at the scene. Unfortunately, the mine surveyor is responsible for recording the scene and is required to explain why critical information was not recorded (Webber-Youngman, *et al.*, 2019). What makes this even more daunting is that a specific area of the scene might only become relevant at a much later stage of the investigation and by that time the scene is no longer accessible to retrieve evidence or has changed (Ren, *et al.*, 2018). A 3D scan of the environment would enable the mine surveyor to extract critical data after the scene is no longer available should questions arise that were not relevant during the initial stages of the investigation. It must be noted that point-clouds are difficult to navigate and there is a need to enhance the visualisation. The power of VR would not only improve the visualisation and the immersion into the scene (Mures, *et al.*, 2016).

Machine-Generated Data: Timestamps and Operational Logs

Critical timestamp data is generated while a winch is in use. This data can be crucial for effectively preventing unwanted events that may lead to winch accidents and fatalities in mines. The WPD winch signalling system serves as an excellent example of a system that produces timestamp data (Di Giacomo, 2020). This data helps us understand the sequence of events and how incidents occur, providing the added advantage of linking specific actions to their corresponding timestamps. Additionally, logging the usage and effectiveness of the WPD system ensures better safety management and incident analysis. Figure 10 shows a snapshot of such a data log.

```
[482]; 2019/02/25;12:36:53; 0062; STATE;;IDLE
[481]; 2019/02/25;12:37:55; 0015; STATE;;STARTUP
[480]; 2019/02/25;12:38:10; 0010; STATE;;READY
[479]; 2019/02/25;12:38:20; 0003; STATE;;IDLE
[478]; 2019/02/25;12:38:23; 0006; STATE;;BYPASS
[477]; 2019/02/25;12:38:29; 0000; STATE;;IDLE
[476]; 2019/02/25;12:38:29; 0015; STATE;;STARTUP
[475]; 2019/02/25;12:38:44; 0002; STATE;;READY
[474]; 2019/02/25;12:38:46; 0012; STATE;;ACTIVE
[473]; 2019/02/25;12:38:54; 0004; SIGNAL;; RIGHT 1 - BELL WIRE
[472]; 2019/02/25;12:38:58; 0002; STATE;;TRIPPED
[471]; 2019/02/25;12:38:58; SIGNAL;; RIGHT 1 - BELL RELEASE
[470]; 2019/02/25;12:39:00; STATE;;IDLE
[469]; 2019/02/25;--:--:--; POWER ON;;SD count of LEFT 01 and RIGHT 01
[468]; 2019/02/25;12:41:10; 0002; STATE;;IDLE
[467]; 2019/02/25;12:41:12; 0015; STATE;;STARTUP
[466]; 2019/02/25;12:41:27; 0003; STATE;;READY
[465]; 2019/02/25;12:41:30; 0016; STATE;;ACTIVE
[464]; 2019/02/25;12:41:43; 0004; SIGNAL;; RIGHT 1 - BELL WIRE
[463]; 2019/02/25;12:41:46; 0014; STATE;;TRIPPED
[462]; 2019/02/25;12:41:47; SIGNAL;; RIGHT 1 - BELL RELEASE
[461]; 2019/02/25;12:42:00; STATE;;IDLE
[460]; 2019/02/25;--:--:--; POWER ON;;SD count of LEFT 01 and RIGHT 01
```

Figure 10. Winch data logging (Di Giacomo, 2020)

The recorded data provides the following details: the sequence number, a timestamp that includes the date, hours, minutes, and seconds of each logged action. The last line lists the actions recorded, such as idle, startup, ready, tripped, and bell release. This information offers insights into the timeline of an incident or accident.

Additionally, the data can be expanded to include the direction of motion (either away, from or towards the winch), the load (measured in watts required for an action), and speed. This information can be used to calculate the potential position of the scraper at any given moment.

Data-Driven Simulations

In the context of aircraft accident investigations, data driven simulations play a vital role in the investigation process to fully comprehend the root cause of the accident (Szczepaniak, *et al.*, 2020).

Simulations of the aircraft take place in the form of numerical modelling; the numerical models are then verified on recorded data during a flight (Kowaleczko, 2005). Figure 11 shows flight velocity recorded data vs simulated from an aircraft. Figure 12 shows the angle of attack from the recorded vs simulated data.

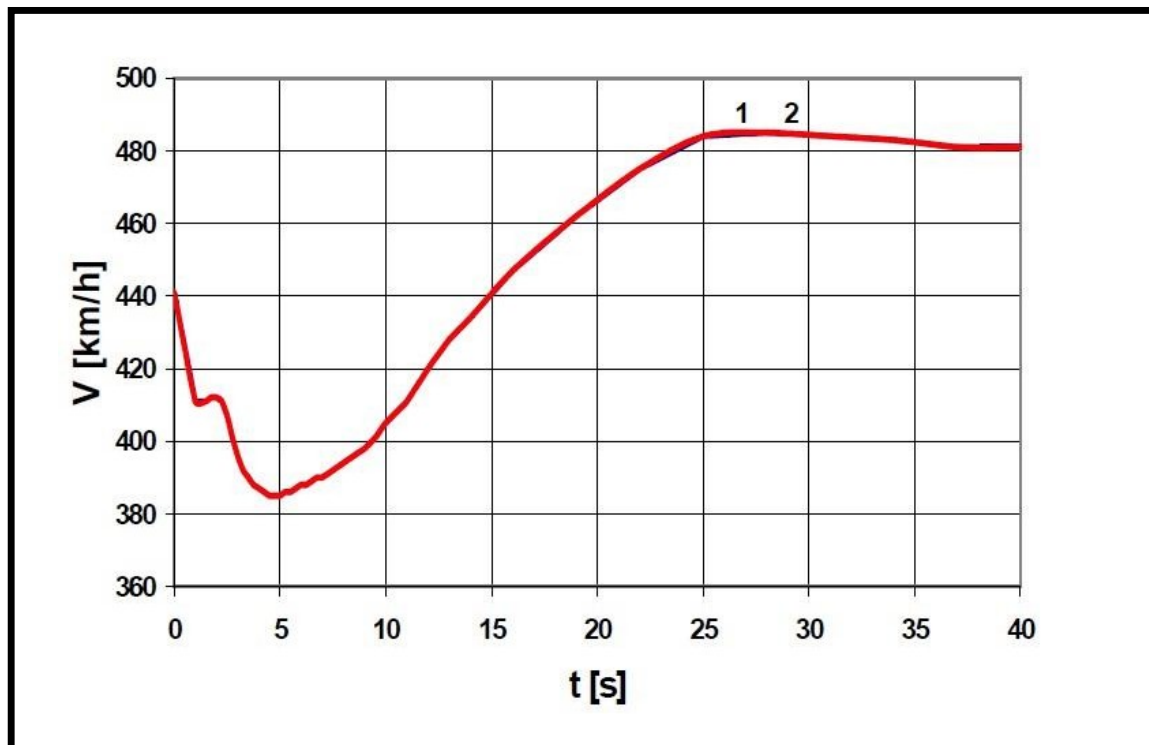


Figure 11. Velocity during a flight vs simulation (Kowaleczko, 2005)

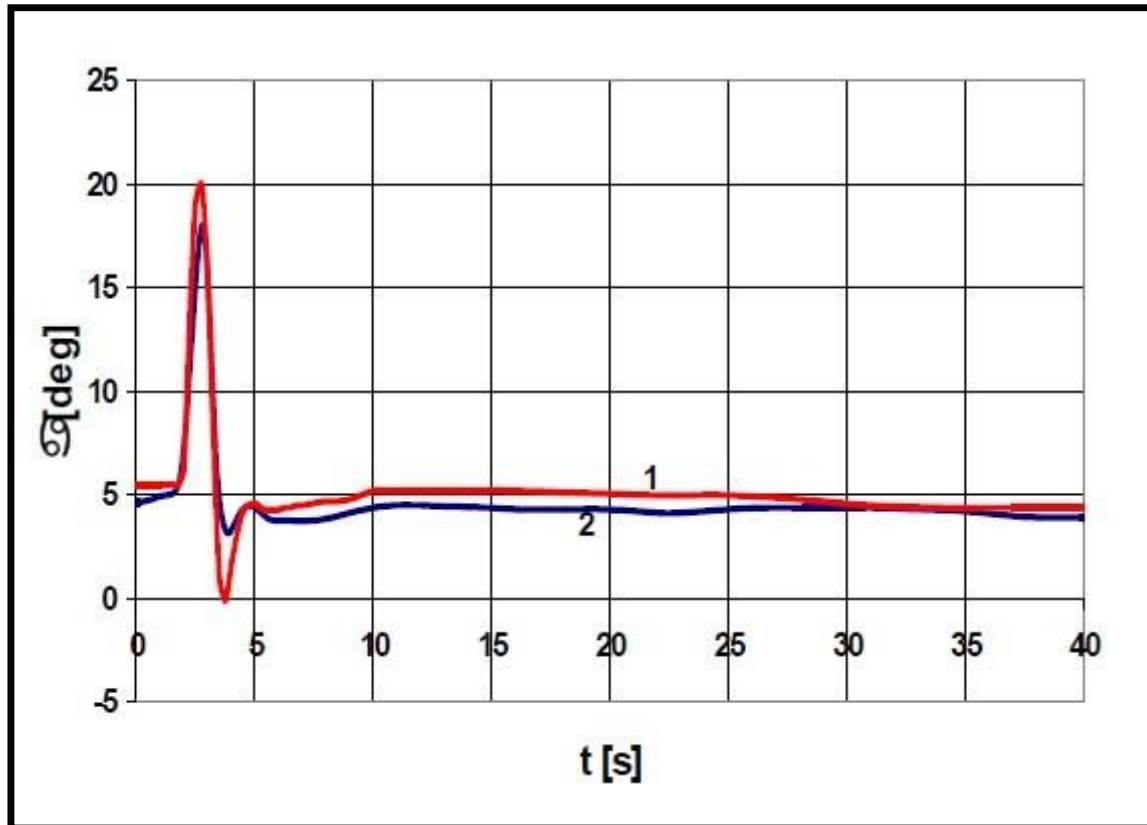


Figure 12. Angle of attack during a flight vs simulation (Kowaleczko, 2005)

Kowaleczko explains that it is possible to test hypotheses about an accident by utilising available data and generating simulations to support those hypotheses. Even with limited data, it is feasible to develop the sequence of events to simulate the accident under investigation. This view is further supported by Szczepaniak, *et al.*, that computer simulations can verify the validity of hypothesis.

INTEGRATION OF ROVS, VR AND DATA-DRIVEN SIMULATIONS AND RECONSTRUCTIONS

Combined Use in Mine Incident Investigations

The goal: Remotely capture critical data that can be processed into a VR scene that can be used as a digital twin of the environment to improve access to data that is currently off-limits for data capturing.

In the context of an incident, although valuable, traditional surveying methods cannot fully inform an investigation (in terms of an accurate, full 3D domain). “Traditional surveying methods may not provide sufficient detail and may exclude seemingly unrelated objects from the final report.” (Grobler, 2020). In addition, there is always the risk of surveyed areas not yet being mapped (Johnson and Fourie, 2023). Hudson (1988) identified the need for an accurate and detailed map during an investigation.

The authors argue that ROVs and VR technologies, accompanied by potential solutions, could enhance incident investigation – by identifying potential critical evidence and improving the efficiency and effectiveness of investigations. The integration of ROVs in mine incident investigations has emerged as a highly effective approach. ROVs play a pivotal role by providing real-time information and data from hazardous and hard-to-reach areas in the mine. The ROV would be under the direct control of the operator as a reconnaissance vehicle, a form of the lowest level of ‘teleportation’ (Li *et al.*, 2022). Equipped with sensor equipment (such as cameras, scanners, and thermal imaging devices), these ROVs enable

investigation teams to gather crucial visual data without directly exposing themselves to risks (Chitikena *et al.*, 2023); (Ulloa *et al.*, 2021).

In a complex incident scenario, a 3D image could also provide mining teams with a better understanding of the safety conditions onsite. Such information can be used to plan access routes, to identify areas to be avoided, and, with subsequent scanning, to possibly monitor structure movement (Grobler, 2023).

The VR environment enhances investigative capabilities by allowing users to immerse a 3D representation of the incident scene. By exploring this virtual space, investigators gain a more comprehensive understanding of the situation. This immersive experience provides them with valuable insights and situational awareness, leading to improved responses and a deeper understanding of the event in question.

Data Capture and Utilisation

Using sensors (attached to mine vehicles) can provide critical information of excavations and all the features contained in the excavation such as support, water and electrical services and ventilation. It may therefore also be used to identify potential areas of deformation. With the advancement of 4IR technologies, mining systems equipped with sensors provide feedback on emissions, gas concentrations, and vibrations. Sandvik Mining and Rock Technology now utilises LiDAR scanners on their 'jumbo' rigs – to orientate the machine and map the excavation. This data can be utilised to provide rescue teams with the most up-to-date information of the scene, assuming it was uploaded to servers before the incident and integrated with the mine survey system (Murrow, 2017).

LiDAR technology plays a vital role in mine incident investigations by monitoring rock formations (Grobler and Pienaar, 2021) and assessing conditions and potential movements (Luhman *et al.*, 2014). This ensures the collection of maximum data during investigations. Ongoing research aims to combine laser scanning data with ground penetrating radar information to create a comprehensive map of expected strata in pillars or solid faces. This integration of data sources shows promise for improving safety measures and enhancing the mitigation of unwanted events based on these insights.

“Wearable technology will have applications in industrial emergency response training, documentation of routes, natural disaster response and terrain assessment. Currently one new backpack innovation combines five cameras with a LiDAR profiler and provides an accuracy of 3 cm in a three-dimensional image” (Woods, 2016). (Grobler *et al.*, 2021).

Training and Simulation

LiDAR and photogrammetric data can be used to reconstruct conditions and animate events based on the information gathered at the scene (Webber-Youngman and van Wyk, 2013). An additional benefit of detailed forensic survey data, captured by an investigation team, is that the investigation documents and records of all information can then be shared – meaning that data and experiences can be disseminated for future training and analyses (Johnson and Fourie, 2023). Laser scanning can record the physical attributes and evidence of the scene of an incident in 3D, that can be converted to 'scaled' CAD drawings (Johnson and Fourie, 2023), accident plans (Luhman *et al.*, 2014) and 3D virtual reality experiences. Infrastructure scanning mitigates risk by having detailed 3D mapping to inform mining strategies, walk-throughs and for training (Lyons, 2014).

This valuable information and data inform simulation modelling, allowing investigation teams to simulate and test hypothesis during the investigation. The combination of the spatial data that enables the digital twin, the valuable time stamped data and the possibilities of simulation models can add value that has not yet been experienced in the mining industry during investigations and the process of learning from incidents.

FUTURE DIRECTIONS

Ongoing Research and Development

Current research and development by the author at the University of Johannesburg (Department of Mining and Mine Surveying) explores the use of ROVs for use in incident investigation processes. The aim of the research is to identify appropriate and available technologies while developing a standard operating procedure (SOP) with recommended technologies, and methodologies, based on the specifications of the required incident investigations.

The needs of investigation teams must be identified and, in a collaborative manner, be discussed between experts, academics and industry leaders; to develop a plan of action in researching appropriate and available technologies for specific conditions (and scenarios) associated with incident investigations. A SOP for the use of ROVs could be developed for mine incident investigations based on the specific task at hand and should be based on previous learnings (and experiences) from similar investigations.

Predictions for Investigation Capabilities

The authors predict that the availability and affordability of ROVs (and associated technologies mentioned in this paper) would be an opportunity for mines in South Africa to explore and utilise, the offerings.

It would be a collaborative effort between private companies, the industry, academics, and other role-players, to enhance the capabilities and efficiency of future investigation operations. We have the special people, and we have special equipment, but the landscape of special equipment has changed and needs to be explored and leveraged, to ensure that investigations of mining incidents unlock the 'black box' of data to ensure we learn from unwanted events to effectively mitigate the recurrence to reach the goal of Zero Ham.

CONCLUSION

Summary of Findings

The increasing complexity of mining (depth, heat, cost, equipment used, mining methods) will lead to more challenging investigations during incidents and accidents. It is therefore of importance to evaluate and embrace new technologies in mine incident investigations – to minimise risk and improve outcomes, emphasising the need for mine investigation teams to remain up to date.

Recommendations for Mine Investigation Processes

To enhance the outcomes from incident and accident investigation processes, the following recommendations are proposed:

- The authors suggest that to effectively mitigate the recurrence of an unwanted event, one must understand the factors that contributed to the incident through incident investigation processes. The incident investigation process is a significant part of understanding the root cause of an event. Unfortunately, current methodologies are outdated and there are recurrences of events. Research has identified a correlation between the safety performance of a mine and the quality of the incident investigations.
- The application of new technology could provide data, evidence, and learning opportunities to the mining industry – hopefully to prevent more incidents.
- The advantages of using VR cameras (in conjunction with photogrammetry applications) have been explored and identified (Grobler *et al.*, 2021). Current research supports the advantages of using VR, 3D scanned data, and photogrammetry applications. It has been recognised that remotely operated robots can conduct dangerous missions, thereby removing human operators from risk (Li *et al.*, 2021). This approach allows for the access and capture of data that has previously been off-limits, which could be crucial for effectively understanding and mitigating unwanted events.
- Simulation modelling within the digital twin of a scene offers valuable opportunities to work

towards achieving Zero Harm. By simulating developed hypotheses during the LFI processes, we can gain a better understanding of unwanted events. Additionally, this approach allows all stakeholders to ‘access’ the scene in question, enabling them to develop and test their own hypotheses alongside others.

- Implementing recommendations can greatly enhance investigation processes, leading to improved safety standards and more effective LFI outcomes.
- The development of a risk management tool that utilises the power of artificial intelligence can be unlocked once the black box of incident data has been recorded and can be used in conjunction with other critical historical data to train a neural network to predict unwanted events before they occur.

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Jaco Johannes van Dalen

Senior Mine Planner
Dayenu Mining Consultants

As a dynamic and innovative mine planner with a strong background in mine surveying, I have built a robust career in the mining industry since 2010, starting with Anglo Gold Ashanti and later advancing to my role as a Mine Planner at Harmony. Backed by 6 years of mine rescue service experience, I bring a unique perspective on safety and emergency response, ensuring that all technological solutions I develop prioritize the well-being of personnel and operational continuity. I am currently working as a Mining Consultant with Dayenu Mining Consultants, a role I have held for the last 2 years, where I continue to apply my expertise in leveraging advanced technologies to optimize mining processes and drive value through creative problem-solving.

Improving occupational health, risk, and safety management: the syncromine risk management software module by Mineware Consulting

W. Minnie

Mineware Consulting, South Africa

The Syncromine Risk Management Software Module by Mineware Consulting is a system for improving health and safety in mining operations. It addresses the challenges and risks of the mining industry, which has seen a rise in fatalities in the last few years. It helps identify, analyse, prevent, and mitigate hazards and risks that affect the organisation and its employees. It uses a holistic risk-based approach and a closed loop control structure to manage and monitor risk at all levels. It is a comprehensive and integrated solution for risk management with AI enhanced assistance that helps the user cover all the bases. With over half a decade of data being analysed at one of our clients we can share some of the successful metrics achieved year-on-year along the journey.

Examples of slideshow:



The Challenge:

Mining is inherently risky, with a multitude of hazards that can jeopardise the safety of workers and disrupt operations. In South Africa, the mining industry has faced significant safety challenges, with increased incidents leading to loss of life and operational downtime. The complexity of managing these risks is amplified by the numerous moving parts in a mining operation, ranging from equipment management to human resources and bonus calculations. These challenges necessitate a system that not only identifies and mitigates risks but also evolves with the changing landscape of mining operations.

The Syncromine Risk Management Software Module by Mineware Consulting is a cutting-edge solution designed to address exactly these challenges head-on. This software is not just a tool, it's a comprehensive, integrated system that allows mining operations to manage and monitor risks at every level. By employing a risk-based approach and a closed-loop control structure, Syncromine ensures that every potential hazard is identified, analysed, and mitigated effectively.

Key Features and Benefits:

Holistic Risk Management: Syncromine offers a complete solution for risk management, integrating various safety modules that can be customised according to the specific needs of a mining operation. Whether it's production audits, safety inspections, or engineering checks, Syncromine brings all critical data into one user-friendly interface.

AI-Enhanced Analysis: The introduction of AI-powered risk mitigation features into Syncromine marks a significant advancement in how risks are assessed. AI Assistants analyse vast datasets from safety inspections, rock engineering assessments, and general checklists to identify hazards and evaluate controls. This automation enhances accuracy, reduces human error, and provides real-time insights, enabling more informed decision-making.

Continuous Improvement through Feedback Loops: One of the standout features of Syncromine is its feedback loop mechanism. Data from various modules feed back into the system, allowing continuous updates and refinements to risk models. This ensures that risk management strategies are not static but evolve in line with operational changes and new insights.

Enhanced Safety and Efficiency: Through its integration capabilities, Syncromine not only improves safety outcomes but also enhances operational efficiency. It allows staff to concentrate on critical tasks with the assurance that the software is continuously monitoring and managing risks proactively.

Data-Driven Decision-Making: With AI-assisted analysis, Syncromine provides a solid foundation for data-driven decisions. It identifies potential gaps in risk assessments, suggests missing controls, and highlights repetitive deviations, ensuring that every aspect of mine safety is covered.

By leveraging AI and comprehensive risk management strategies, Mineware Consulting is helping to create safer, more efficient mining operations. As we continue to face challenges in mine safety, solutions like Syncromine are crucial in our collective effort to safeguard lives and improve the industry's safety standards.

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Werner Minnie

Head of Business Development
Mineware Consulting

Werner Minnie is an accomplished professional with over two decades of experience in the mining and software sectors, specializing in Mine Technical Systems, and business development. His career journey began in IT infrastructure and project management, where he played a pivotal role in implementing critical systems within the mining industry. Over the years, Werner advanced into leadership roles, including Mine Planning Manager at Gold Fields and Head of Business Development at Mineware Consulting, where he has been instrumental in driving growth, establishing strategic partnerships, and delivering tailored software solutions to clients such as Anglo Gold Ashanti, Harmony Gold, and Sibanye Stillwater.

Renowned for his strong client relationship skills and deep understanding of technical systems in mining, Werner has continually aligned business and technical strategies to meet evolving market demands. His expertise spans consulting and the integration of complex mine technical systems, making him a key figure in supporting and advancing the technological needs of the mining industry.

