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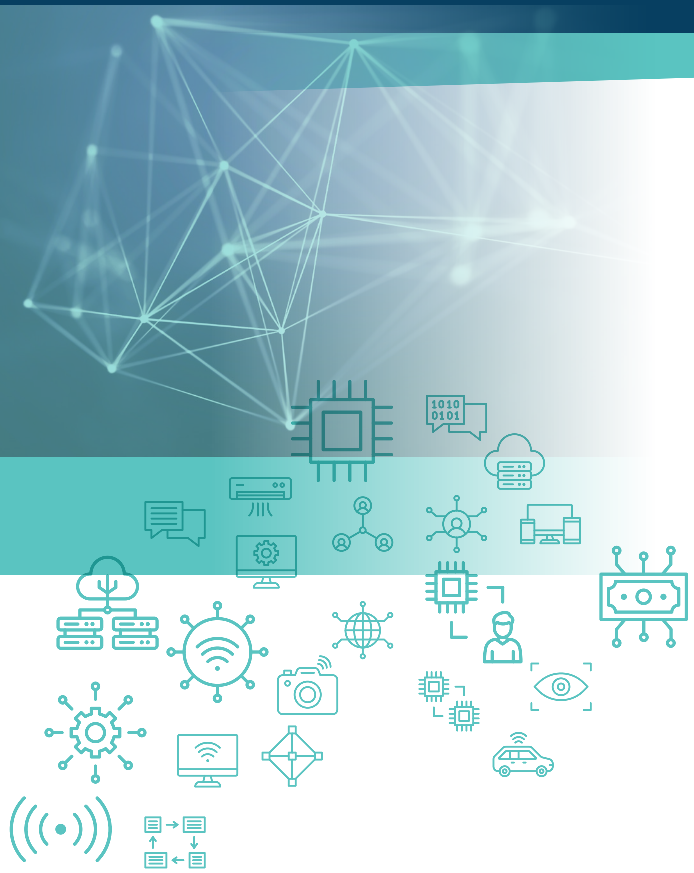
DIGITAL TRANSFORMATION IN MINING 2023

28-29 JUNE 2023
THE CANVAS, RIVERSANDS, FOURWAYS

SAIMM
THE SOUTHERN AFRICAN INSTITUTE OF MINING AND METALLURGY

Putting digital technologies to work



Proceedings

THE SOUTHERN AFRICAN INSTITUTE OF MINING AND METALLURGY
JOHANNESBURG 2023

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FOREWORD

25 years ago, we were teaching operational personnel to turn computers on and off. Now their grandkids are saying, ‘There’s an app for that’. This is impacting mining too. Transformation is happening whether you are ready or not. But not by itself. It’s being made to happen.

What do we want to transform? We want to transform people’s behaviour, and the way we gather information. Why? We want to be safer and more productive. We want to change the way we take decisions. We even want remote control and automation.

This conference will be a showcase and learning experience for you to be challenged and informed, and hopefully, to leave excited to be a part of mining’s digital transformation journey. You will experience notable keynote speakers and a showcase of digital technologies, live demonstrations, and the opportunity to network. Look, listen and learn. The future is happening, now!

I hope you find the occasion useful.

Many thanks to an able committee and SAIMM secretariat.

Mike Woodhall
Conference Chairperson

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Requirements of real-time information management systems for the minerals sector

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Remote and automated operations in the minerals industry are potential solutions to a sustainable and efficient supply of minerals and metals. Access to data and information with minimal latency (real-time) is inevitable towards pervasive remote and automated operations in the minerals industry. Hence, the concept of real-time information management systems (RTIMS) is receiving increased attention in the industry and among stakeholders. However, because RTIMS for the minerals industry is only emerging, and that it is a system of systems, issues of the target readiness and performance metrology are topics of ongoing research. Here, we provide and present necessary components of RTIMS that are tailored to the needs of the minerals sector, such that an organisation can progress to higher levels of maturity. We specifically consider a wholistic approach in the planning and scoping of RTIMS for the achievement of a connected mine of the future. It is expected that this work will serve as a reference model for stakeholders to facilitate planning towards connected mines.

INTRODUCTION

The minerals sector enables the global economy, contributing significantly to the growth and development of various industries (., Olalekan *et al* 2016; Fan *et al.*, 2017; Upadhyay *et al.*, 2021). The demand for natural resources is projected to increase massively due to modern drivers such as 'climate extractivism' (Le Billon, 2021). Achieving safer, more efficient and sustainable supplies of raw materials will require an evolution of the minerals sector. To this end, transformation of the minerals sector and particularly mining towards high operation agility, execution and outcome certainty, as well as dynamic system-level feedback and control are likely unavoidable. Particularly, there are increasing desires to explore the adoption of remote-controlled and autonomous systems, leveraging online digital and data-driven controls, including artificial intelligence (Ghorbani *et al.*, 2023a). However, their adoption in an integrated and productive manner necessitates an extensive re-thinking of requirements, such as those along key domains of infrastructure, human resource, organisational culture and business integration. For example, infrastructure alone requires a substantial re-engineering to meet the reliability, bandwidth and latency requirements of real-time monitoring and remote control.

A general concept of real-time information management systems (RTIMS) is highly applicable as a framework to modern management of systems and information in the minerals sector. The concept is also an indicator of digital transformation and its success, because RTIMS is a system of systems and exists at the highest level of management. Hence, its maturity is affected by the maturity of all sub-systems, business processes and management capability. Consequently, RTIMS maturity is a critical indicator of the modern capability of the minerals sector, and hence its readiness to adopt current and emerging technologies (Jaipal *et al.*, 2003; Thuraisingham, 2004; Zheng *et al.*, 2013; Qi, 2020). RTIMS are designed to collect and process data in real-time, providing timely information for decision-making.

The maturity of RTIMS for the minerals sector is still in its early stages, with many companies still relying on, or exploring ways to move away from manual processes regarding data collection and management. Key indicators of maturity of RTIMS are their level of development and adoption. A mature RTIMS can provide real-time data analytics and support decision-making processes using multifaceted tools and sensors that are capable of collecting, transmitting and visualising complex to big data (Adjiski *et al*., 2019; Barnewold and Lottermoser, 2020).

The requirement to achieve a high level of maturity of RTIMS for the minerals sector can be found along several main enabling domains such as technology (Habeeb *et al*., 2019), data quality and management, organisational culture and human resources. These requirements must be adapted to the specific conditions of the minerals sector that are not found in other industries, such as commerce. For example, technologies involved in the minerals sector must be effective and reliable with respect to harsh environmental conditions (Xie *et al*., 2022). The adoption of online sensors and machine learning (and by extension, edge computing) can improve the maturity of RTIMS for the minerals sector (Lv and Li, 2021). Consequently, accurate and reliable data combined with rapid data analysis through machine learning is critical to enable decision making, because of the abundance, volume and complexity of sensor and other forms of data (Ghorbani *et al*., 2023b). The adoption of data standards and procedures through formalised data management (and quality management) can improve the maturity of RTIMS for the minerals sector. This is because data is easily usable, interoperable and fit for the purposes of RTIMS. The culture of an organisation also controls the maturity of RTIMS, because ultimately, systems such as RTIMS are designed for human interaction and the effectiveness of people (e.g., capability and knowledge) drives the effectiveness of RTIMS implementation and evolution, wherever they are deployed. In the most essential case, availability of skilled personnel to implement, manage and operate RTIMS is essential for its maturity. Furthermore, an organisation that prioritises data-driven decision-making, operational efficiency and has a culture of continuous improvement is more likely to reach a mature RTIMS implementation (Iqbal *et al*., 2021). Thus, the cultivation of a data-driven culture can improve the maturity of RTIMS for the minerals sector. Consequently, the cultural aspect implies that the minerals sector requires a range of skills, including data analysis and interpretation, and the ability to command advanced technology (Kopetz and Steiner, 2022). For existing organisations, the development of training programmes and the recruitment of skilled personnel can improve the maturity of RTIMS for the minerals sector.

In the minerals sector, the value of RTIMS lies in its ability to enable real-time (or just-in-time) data analytics, which extracts value in the form of actionable information from complex, high velocity and abundance, and variably structured data. The derived information empowers companies to make data-driven decisions for business operations such as production, sequencing and stockpiling, monitor and maximise worker health and safety, and plan equipment maintenance (e.g., via predictive maintenance through sensor data analytics). Management functions under real-time conditions minimises financial penalties associated with planning using limited certainty regarding the present state. This is because planning could occur for shorter operational or time intervals, and extrapolations into future unknown conditions can be minimised and therefore planning errors can be minimised. Additionally, uncertainty mitigation occurs through additional insight generation, because organisations can use RTIMS to continuously monitor and analyse data, data-mining trends and patterns that would not be apparent through traditional methods. This enhances business performance and reduces downtime by enabling organisations to rapidly respond to issues by executing remedial actions and make well-informed decisions (Savolainen and Urbani, 2021). Consequently, it is possible to further optimise complicated and often co-dependent operations that are typical of the mining industry (Robert *et al*., 2022). This implies that RTIMS can help organisations in the minerals sector improve their return on investment (ROI) through risk reduction, and more granular control in planning, execution and regulatory compliance. This is important because the minerals sector is a capital-intensive and risk-aversive industry, with high costs associated with exploration, extraction and processing (Ali *et al*., 2021; Mutanga *et al*., 2021). In the long term, data compilation combined with post-hoc analysis can help organisations to identify hidden issues (e.g., through quantitative auditing), opportunities for process optimisation, reducing costs and improving overall efficiency.

In this paper, we examine the required components of RTIMS at a high level in the minerals sector and identify the factors that influence their effectiveness. Precisely, the aim of this paper is to provide the fundamental required elements that would be indicative of a mature RTIMS framework. This aim is fulfilled by first identifying the drivers and enablers of the concept of RTIMS. After which, the data-centric characteristic of RTIMS is used to determine the base integrated framework that indicates the maturity of RTIMS.

DRIVERS AND ENABLERS OF RTIMS

The successful deployment of RTIMS depends on several factors that drive their needs and enable their implementation. In this study, drivers refer to factors that necessitate and define the need for RTIMS, while enablers are considered as factors that will directly deliver the value of RTIMS. It is important to note that while drivers may be the primary requisites, these factors (drivers and enablers) are complementary, hence the arrows linking them, in Figure 1.

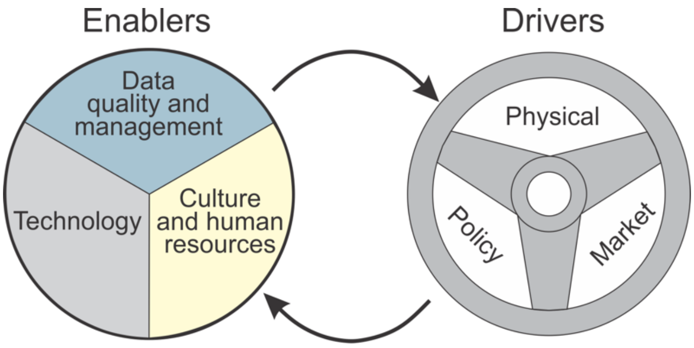

Figure 1. Divers and enablers of RTIMS.

Drivers of RTIMS

Drivers of RTIMS adoption in the minerals sector can broadly be divided into physical, market and policy drivers (Figure 1). Physical drivers pertain to natural physical characteristics of an orebody or mine. Market drivers pertain to the conditions of the market system. Policy drivers pertain to the policy environment under which the minerals sector operates, including the informal economy.

Physical drivers for the use of RTIMS in mining include:

(1) Exhaustion of shallow, large and easily extracted mineral deposits. Increasingly deeper and challenging extraction conditions necessitate better control and monitoring, likely more automation, more efficacious extraction and material separation (Ghorbani *et al.*, 2023a).

(2) Transition toward lower grade deposits. Current average global copper ore-grades are around 0.5%, to as low as 0.26% copper, compared with about 4% in the year 1900 (Mudd, 2009; Mudd and Jowitt, 2018). In addition, a report by (Auctus Metal Portfolios, 2022) showed a weighted grade decline of platinum group metals (PGMs) of 30%, between 2007 and 2020. Thus, enhanced extraction, processing and beneficiation efficiency through enhanced control is important to maximise the business profit margin.

Market drivers for the use of RTIMS in mining include:

(1) Rapidly increasing and diversifying demand for raw materials creates competition and a market for technological solutions (Ganeriwalla *et al.*, 2021; Ghorbani *et al.*, 2023b; Phoke and Khandelwal, 2021). Demand is currently driving companies toward more timely and granular control of production variables, such as extraction sequencing, stockpiling, scheduling and dynamic cut-off grades (Nwaila *et al.*, 2021).

(2) The desire to create transparent and trackable supply chains and perform actions ethically (Ghorbani *et al.*, 2022; PricewaterhouseCoopers, 2021). This increases the need for integrated and pervasive evidence-recording systems that could be leveraged to demonstrate corporate social responsibility, where required.

(3) Continued accumulation of data towards big data, especially through the deployment of online sensors and sensor repurposing (e.g., soft or virtual sensors), combined with the desire to leverage such data (e.g., through analytics) to derive positive business outcomes (e.g., Ghorbani *et al*., 2022). This necessitates modern data lifecycles or pipelines (from data generation to management to usage and deprecation).

Policy drivers for the use of RTIMS in mining include:

(1) Increasing regulatory requirements. This increases risk of business non-compliance, which is mitigated by RTIMS. The integration of systems under the RTIMS concept implies that activities of organisations can be recorded and accessed through RTIMS for regulatory compliance, such as filing of reports and auditing.

(2) Shifting policy environment towards adoption of informal economic frameworks to attract investment and conduct business (e.g., social licence to operate; Prno and Slocombe, 2012; Meesters *et al.,* 2021). To demonstrate the ability to meet extra-economic business ethical commitments, RTIMS would be required to record business activities to demonstrate ethical virtue.

(3) Global awareness of sustainability concerns in natural resource usage (European Commission, 2011, 2014, 2017, 2020; Schulz, 2017; Government of Canada, 2022). Business capitalisation on emerging global trends is important to ensure business survival, especially awareness of emerging concerns with the supply of critical raw materials (e.g., Rachidi *et al.,* 2021). RTIMS assist business resource allocation to maximise profits amidst global changes in consumption patterns.

Enablers of RTIMS

The enablers of RTIMS correspond to characteristics/assets of an organisation, that if fostered or acquired, could facilitate the adoption and progression of RTIMS. These characteristics can be divided into the following areas: technology (Habeeb *et al*., 2019), data quality and management, organisational culture and human resources (Figure 1). These are further detailed below.

Technological enablers include *(Ghorbani et al., 2022, 2023b):*

(1) Cheap, practical and robust sensor networks, such as the Industrial Internet of Things (IIoT), soft or virtual sensors, sensor networks and edge computing devices.

(2) Range of non-wired telecommunications technologies that include wireless and light-based networks.

(3) Big data analytics, artificial intelligence, machine learning, digital dashboards and other data-driven tools.

(4) Mechanisation, automation and remote operation solutions.

Data quality and management enablers include *(Qi, 2020):*

(1) Standardised data management and governance.

(2) Data quality standards and tools.

Organisational culture and human resource enablers include *(Lööw et al., 2019):*

(1) Digital and data skills (especially discipline-specific and trans-disciplinary epistemology).

(2) Programming and automation skills.

(3) Sensor, infrastructure, data and software engineering skills.

(4) Business integration, engagement and innovation skills.

(5) Agile, adaptive and motivated workforce.

(6) Informed and modern-minded management.

PROPOSED INTEGRATED RTIMS REQUIREMENTS MODEL FOR THE MINERALS SECTORS

Data-centricity is perceived as a solution to achieving digital transformation, which also is the base input for RTIMS in the minerals sector. However, the value to RTIMS regarding the huge amount of data that is generated from the various sections of the mining value chain can only be realised when the base requirements are achieved. Against this backdrop, we identified four fundamental elements that contribute to extracting value from data, as well as defining the maturity of RTIMS for the minerals sector. These four elements, summarised in Figure 2, are: (1) infrastructure; (2) data and information management; (3) data usage; and (4) the organisation culture and human resource. The data usage aspect is not discussed further here, because it is fully discussed under the concept of 'dry labs' for the minerals sector in Ghorbani *et al.*, 2022 and 2023b. Specifically, the types of talents that would be required in addition to existing skilled personnel include geodata scientists, who are primarily trans-disciplinary data specialists.

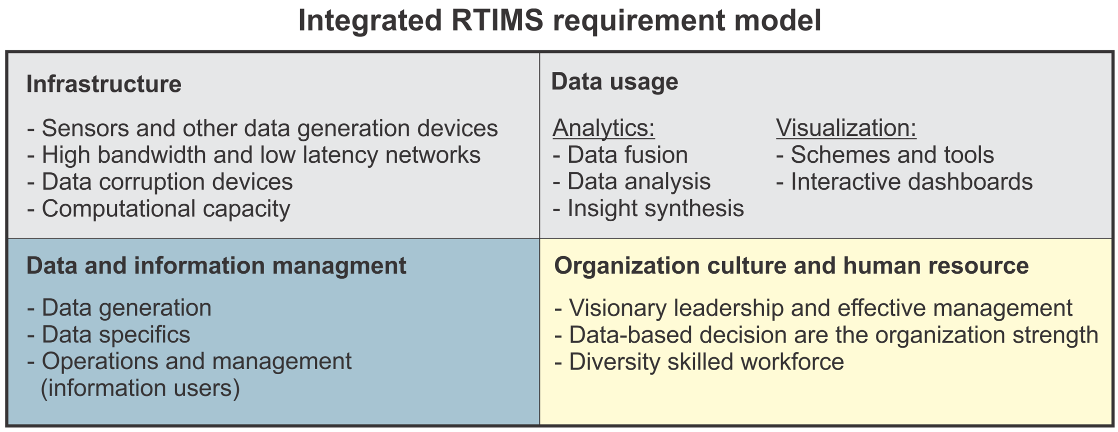

Figure 2. Basic elements defining RTIMS maturity.

Infrastructure

RTIMS is demanding on the quality of infrastructure, hence, infrastructure maturity is critically related to the upper-bound capability of RTIMS. In the minerals sector, particularly in the mining environment, the capability of the infrastructure is greatly controlled by the environmental conditions that include geotechnical stability and remoteness of the operation. Infrastructure in the minerals sector has generally been engineered to the purpose of non-real-time control systems and pre-IIoT in terms of sensor abundance (Ali *et al.*, 2021; Mutanga *et al.*, 2021). In an RTIMS-enabled environment and with the deployment of IIoT, the amount of data that needs to be transmitted and analysed is potentially at the level of big data. This means that infrastructure must be designed with an *a priori* consideration of the characteristics of big data and big data analytics. This infrastructure is intended to connect sensors, data storage and management systems, data users, data analysts and management. It requires hardware, software and information communication systems that interconnect sensors, physical transport layers, computers, servers and potentially dashboard or web (although not necessarily externally accessible) portals. RTIMS's tremendous demand on the quality of the infrastructure results from its need to access multiple types of data, including online and live sensor data, which requires a combination of high bandwidth and low latency (Ghorbani *et al.*, 2023b). The high bandwidth allows data to be transported with minimal loss or decimation, while the low latency enables data to be analysed and controlled to be enacted with minimal time lag. For example, remote control requires streaming of video and acoustic sensor data, which are bandwidth-heavy. However, the control of remote devices requires low communication latency because actions should occur with minimal delay. Management and governance of infrastructure is not discussed here, as those topics are unspecific to RTIMS but are typical topics in data and information management and information technology.

Key components of an infrastructure that would be suitable for RTIMS implementation based on currently available technology include: (1) sensors and other data generation devices; (2) high-bandwidth and low latency networks; (3) data curation devices; and (4) computational capacity. Sensors allow collection of data, and in the case of online sensors, data can be generated as a stream. Periodic or ad hoc data generation devices, such as portable instruments and manual data entry devices are already deployed throughout the minerals sector and would likely continue to generate targeted data. A key requirement of sensors in the minerals sector in general is that they must be designed to withstand environmental conditions that potentially include (non-exhaustively) high temperatures, causative and reactive gases and liquids, vibration and abrupt accelerations, dust and humidity.

Network requirements are probably the most difficult to meet in the mining environment because infrastructure deployment is contingent on the availability of space and requires exceptional forward planning ahead of implementation. Some current and promising solutions include fibre optic cable-based networks, powerline networking and LiFi networks (Kolade & Cheng, 2022; Shimaponda-Nawa *et al*., 2022; Smith, 2020). In more industrial settings, such as mineral processing plants, meeting requirements around networking is not challenging because a range of industrial solutions are already available for engineered and hospitable environments. However, this is not so, particularly for the underground mines, due to various environmental conditions that attenuate communication signals.

Data curation devices are likely to reside outside of the data generation zones, because data curation technology, such as storage devices, are far less tolerant of environmental conditions, and require a regulated interior environment to maximise functionality and reliability. Hence, the requirements on data curation devices are more controlled by the deployment needs around typical information technology considerations (e.g., of capacity, redundancy and concurrency) than environmental considerations (e.g., vibration and impact resistance, and temperature range).

Computational capacity, like data curation, is likely to occur remotely to data generation zones, which implies that their characteristics are also shaped by specific computational needs (e.g., of performance, reliability and scalability) rather than environmental needs. Existing solutions for computation that include cloud computing, high performance workstations and even portable computing devices may suffice. This aspect also includes software provisioning, such that necessary software to conduct key functions such as data analytics, dashboarding, remote control and automation are available and fit for purpose.

Data and Information Management

RTIMS necessitates a bi-directional transfer of data and information. A functional depiction of RTIMS resembles a triangle (Figure 3). At the apex lies data generation, which includes sensors and other data generation devices while at the left base vertex are data users and specialists. Finally, at the right base vertex lies information users and operation specialists who receive distilled information from raw data and provide feedback and control. Because of the increasing specialisation in various domains, functional roles, such as data generators and users, do not generally overlap in terms of expertise. For example, a sensor technician would not be a machine learning engineer and vice versa. This implies that specifications around data and information must be engineered in a formal system, which is the data and information management system. This system takes on the task to engineer and deliver data in one direction, to data and information users, and receives specifications and high-level guidance from data and information users; and in the other direction, to data and information generators. The system's role is to ensure that data and information are fit for purpose (e.g., accurate, timely and of relevance to a task), and are accessible by those in need. Hence, data and information management is a human-oriented counterpart to the infrastructure component. This ensures that the infrastructure component is maximally productive through engineering data and information in a manner that is the most useful. Management of quality, standardisation of protocols, metadata and types of sensors, structure of manually inputted data, etc., are of primary functionality to data and information management, alongside infrastructure improvement, planning and implementation.

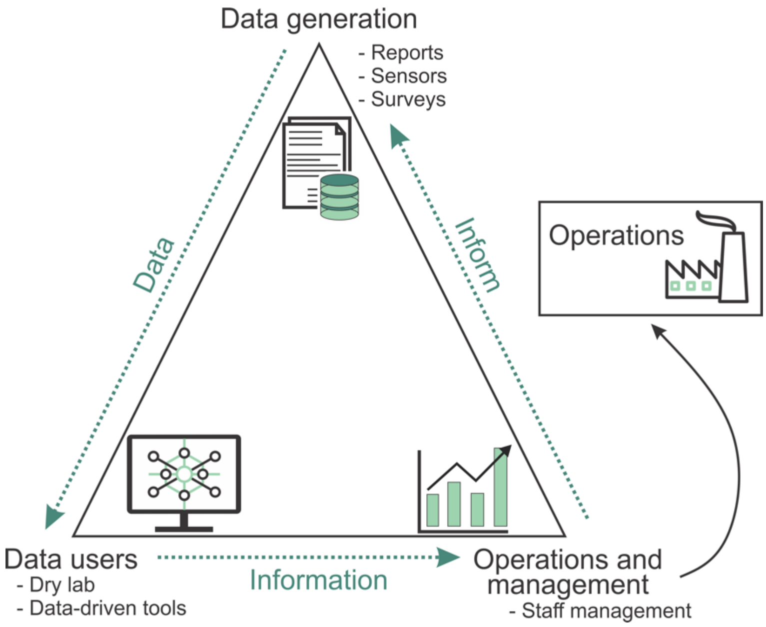

Figure 3. RTIMS information and data management in the minerals industry.

Data Usage Specialists - Analytics and Visualisation

Data users form a key component of RTIMS. Since the real-time aspect requires substantial data fusion, analysis and insight synthesis, capable human talent who are data savvy are important to extract value from the infrastructure and data. The goal is to transform various forms of data, including manually derived data (e.g., assays) and sensor data (e.g., ambient seismic data) into actionable insights (e.g., impending rock movement) (Gravel, 2022). A key requirement that is easy to overlook is skilled personnel who are adept at epistemology, who can assist with data engineering and guiding geodata scientists in the use of data and assessments of their results. Epistemology specialists tend to be discipline-specific experts, such as geochemists, metallurgists, geostatisticians, geophysicists, etc., because they are trained in the methods of data generation and metrology. Additionally, visualisation is intended to ensure that complex, multi-dimensional information and their uncertainty can be visualised and therefore be unambiguously understood by humans to act on the conveyed information. To accomplish this effectively, the talent should include: (1) data and sensor engineers; (2) data analysts and scientists; (3) data visualisation specialists; and (4) business analysts. Data and sensor engineers can create streams of data that best capture business processes or environmental conditions. Data analysts and scientists can best derive value from engineered data types, to extract information of relevance to business outcomes. Data visualisation specialists can create effective visualisation schemes and tools, as well as dashboards to ensure that information is presented in a visually comprehensible and technically accurate manner. Finally, business analysts can translate business needs, management metrics, capability and other non-technical aspects of business processes to data specialists. This ensures that actions around data serve the greater goal of business performance. Hence, presented dashboards of information not only contain technical and operational insights, but potentially also show how they impact the business in terms of financial metrics or in achievement of a specific goal.

Organisation Culture and Human Resources

Culture and human resources are also critical components of RTIMS. However, these aspects (or 'soft' requirements) are hard to define because the variability with respect to each organisation's culture and its current state of human resources, is high. The requirements of the culture and human resources can be contextualised in terms of the requirements of infrastructure, data analytics and visualisation, which are hard requirements in that they can be precisely defined and implemented to specifications. In this sense, an organisation's required culture and human resource should be one that is adequately capable of leveraging the RTIMS infrastructure and utilises data to derive the type of information required and therefore fulfil the needs of the RTIMS users.

Generally, a culture that is highly technological, data literate and motivated to experiment using data, sensors and systems (from generation to usage), is more desirable towards successful RTIMS implementations. As such, RTIMS requires a diverse workforce that is fluent not only in traditional mining fields (e.g., geologists, mine engineers, geometallurgists) but also in computational disciplines (e.g., engineers, analysts, geodata scientists, data scientists), business integration specialists and data and information management system specialists (e.g., quality systems engineers).

Business integration and data and information management specialists are necessary to ensure that data and information interoperability is achieved, and that systems that are implemented demonstrably derive a better business performance through objective assessments. At the management level, human resource specialists and the senior management team should have a functional awareness of all areas in order to provide direction (Humphreys, 2015). Without effective management, visionary leadership and adequate technical competence, it would be difficult for culture change to occur. It is important to note that technical domains are evolving rapidly, enabling stakeholders to make independent decisions aided by data and artificial intelligence. As such, 'board to floor' alignment of strategies in the minerals sector that tends to be conservative and managed hierarchically, is crucial for RTIMS implementation.

CONCLUSION

The real-time aspect of systems is a challenge in the minerals sector, particularly in remote and environmentally challenging conditions. This is particularly true of the extractives industry, predominantly for underground mining. Effective deployment of autonomous and remote-controlled systems will depend on the capability or maturity of an organisation's RTIMS, because RTIMS is a system of systems and its maturity is indicative of the maturity of various sub-systems, including operation control and environmental monitoring systems. The requirements to achieve a high level of RTIMS maturity are primarily within key domains that include technology, data quality and management, organisational culture and human resources. Development in these domains with a goal to achieve system modernisation translate to enhanced RTIMS maturity, which in turn, implies that the organisation is more likely to be ready to adopt current and emerging solutions.

ACKNOWLEDGEMENTS

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Her research interests include development of RTIMS frameworks and models for the minerals and extractive sector, visible light communications (VLC), powerline communications (PLC), and optical fibre communications (OFC).

Adoption of wireless sensor networks by South African mines

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Wireless Sensor Networks (WSN) can alleviate the challenges faced by South African mines, which include declining grades, environmental pressure and low labour productivity. The purpose of this study was to investigate the level of adoption of WSN by South African mines and determine the factors influencing adoption. A combined Innovation Diffusion Theory and Technology Organisation Environment framework was used as the conceptual framework for evaluation, with convenience sample being used to collect data by online questionnaire. Data was analysed using correlation and multiple linear regression modelling. One major finding of the study was that WSN adoption levels increased when evaluating managers learned that other mine sites had already adopted similar technology. This study recommended that future research could limit the focus to mine personnel and may be important for understanding the levels of smart mining adoption.

INTRODUCTION

Wireless Sensor Networks (WSN) can be deployed to measure and control parameters such as temperature, fluid level, pressure, spacing, air flow and concentration of particulate matter in the air, and a host of other parameters (Ha´c, 2003). When integrated with artificial intelligence and connected to the internet, WSN are capable of measuring and relaying information operators for interpretation (Tang *et al.*, 2018). By virtue of their ability to connect physical objects with humans, WSN are an enabler of smart production systems (Ahmadi *et al.*, 2018).

Background to the Research Problems

Technological breakthroughs have improved power usage, communication, memory and processing capacity of WSN (Ha´c, 2003) enabling their use to be widespread across various industries, including mining, where they make the work of humans safer, more efficient and productive (Chehri *et al*., 2011). It is on this basis that this study was conducted, to determine the extent to which WSN has been adopted by South African mines.

Statement of the Research Problem

Although higher levels of WSN adoption are known to increase sustainability and profitability for mines (Job and Mcaree, 2017), studies point to current adoption levels being low (Gangazhe, 2016, Williams, 2020). At the current levels of adoption, South Africa's mining industry faces the following challenges:

Declining grades: low grade ores drive existing mining operations to greater depths where the mineralogical and structural properties make extraction using current mining methods and technology uneconomic and unsafe (Jacobs, 2017).

Environmental protection pressure: environmental sustainability goals force surface mining operations underground to reduce the degradation of the environment (Hesketh, 2021). Without implementing innovative technology safe extraction at extremely shallow depths is challenging.
Low labour productivity: Low productivity levels plague South African mines while that of global peers rises dramatically with increasing adoption of advanced technology. This may affect the country's prospects of attracting foreign direct investment in the future (Ediriweera, 2021).

Purpose of the Research
The purpose of the study was to determine the level of WSN adoption and the factors that affect the adoption level. Finally, a model was developed which can be used to assess a mine's readiness to adopt WSN. A combined Innovation Diffusion Theory (IDT), Technology Organisation Environment (TOE) framework was used as the theoretical basis for the investigation.

Research Objectives
The following objectives were proposed for this study:

- To determine the level of adoption of WSN by South African mines.
- To investigate the influence of the adoption levels of WSN in South African mines.
- To develop a model for evaluating the readiness of South African mines to adopt WSN technology.

Research Questions
This study has endeavoured to answer the following questions:

Q_1. What are the levels of adoption of WSN by South African Mines?
Q_2. What are the factors influencing adoption levels of WSN by South African Mines?
Q_3. What are the ways in which adoption levels of WSN on South African mines can be improved?
Q_4. How can stakeholders assess the readiness level of mines to adopt WSN based technology?

Limitations and Delimitations
This study was limited to South African mining companies. The use of convenience sampling to select the respondents affected the size of the sample and reduced the generalisability of this study's findings (Bougie and Sekaran, 2020). Lastly, this study sought to identify factors that affect the adoption of WSN by mines in a cross-sectional time horizon, therefore, determining causal relationships between the variables was beyond the scope of this research.

LITERATURE REVIEW

Smart Mining Technology
Organisations such as the smart manufacturing leadership coalition in the United States of America lobby for Smart production, which has resulted in high levels of adoption of modern advanced manufacturing technology in the USA, Europe and parts of Asia (Thoben *et al*., 2017). The smart production approach is not unique to manufacturing, the applicability of the concept in mining is also widely accepted (Ge, 2018). Smart Mining entails visualising, monitoring and managing mining operations remotely (Yu-Fang, 2011). The availability of real-time data and automation in mining transitioned mining operations from traditionally unpredictable, complex and high-risk operations (Chaykowski, 2002) to transparent, predictable and efficient production systems that have the flexibility and resilience to handle the shocks of volatile commodities markets (Bassan *et al*., 2008).

Wireless Sensor Networks
Wireless sensors are small devices that measure, monitor and control parameters in a physical environment (Hancke, 2012). Their advantage over wired sensors is lower material, installation and maintenance costs (Chintalapudi *et al*., 2006). WSN are formed by connecting distributed wireless sensors to retrieve and relay data from a specific environment (Ahmadi *et al*., 2018). Wireless sensors, also referred to as nodes or motes, are miniature battery-powered devices incorporating a sensing unit, processing unit and low-power radio for communication.

The adoption of WSN based technology in mining is driven by the need to improve worker safety, productivity, and efficiency. In Ndoh and Delisle (2005), WSN were used to determine real-time position of people and mobile equipment underground. In the study, WSN were integrated with wireless local area network (WLAN). The results of the study proved that location tracking was possible using WSN. Ground movement monitoring was investigated using a "Structure-Aware Self-Adaptive" WSN (Li and Liu, 2007). The findings were that the WSN system was able to detect fall of ground. WSN integrated with LAN or WLAN were investigated for detection of fires and measurement and monitoring of temperature, humidity, noxious fumes, carbon monoxide, carbon dioxide and methane (Chehri *et al*., 2011, Tao and ZXiaoyang, 2011, Abu-Mahfouz *et al*., 2014). Tao and ZXiaoyang (2011) investigated the use of WSN integrated with WLAN for environmental monitoring, relaying data to a control base.

These studies confirmed the efficacy of WSN based technology in making work safer and more productive.

Review of Prior Literature on Adoption of Technology

All the articles studied are based on either technology adoption, diffusion or both. Therefore, the articles reviewed in this section are in alignment with the approach adopted in this research, which is to integrate IDT and TOE models to understand the factors that influence the adoption of WSN. The variables measured were adopted from previous literature that used these models, with minor modifications to suit the context of the study, i.e. the location, industry, or technology focus of the study. This is an important consideration when conducting a study of the South African mining industry so that the peculiarities that make South Africa distinct from other mining jurisdictions can be considered. The influence of labour unions, mining management and safety regulations, and the mix of manual and mechanised mining methods are prime examples.

Technology Readiness

Technology readiness has been investigated in several studies encountered in the review of the literature (Duang-Ek-Anong *et al.*, 2019, Alanazi and Soh, 2020, Dewi *et al*., 2018, Fang *et al*., 2019, Gumbi and Twinomurinzi, 2020). The findings of these studies highlight the importance of organisational readiness for technology adoption. Factors including budget, awareness, skills and management support within the organisation are of high importance as indicated by Krishnan and Wahab (2019) who investigated the adoption of smart warehousing in Malaysia, Dewi *et al*., (2018) who approached readiness of the smart city concept from a TOE framework point of view; as well as Gumbi and Twinomurinzi (2020) who investigated the adoption of smart manufacturing in SMMEs. From an environmental point of view, collaborations, and support from third-party organisations were found to influence adoption and reduce barriers such as cost and skills availability whilst functional requirements of the municipality and compatibility with existing and technology were key determinants of technology readiness (Dewi *et al*., 2018).

METHOD

The research model selected for this research, shown in Figure 1., consisted of a combination of IDT and TOE. This model was selected on the basis that scholars had applied a combined IDT, TOE model in prior research of adoption at an organisational level and found it to have predictive efficiency for technology adoption. In this research WSN adoption was the dependent variable under investigation. The model permitted evaluation of variables that managers typically consider when making business decisions in the day to day running of a mine, categorised as technology, organisation, and environment constructs. The research model comprised three factors that were hypothesised to influence a mine's adoption of WSN positively.

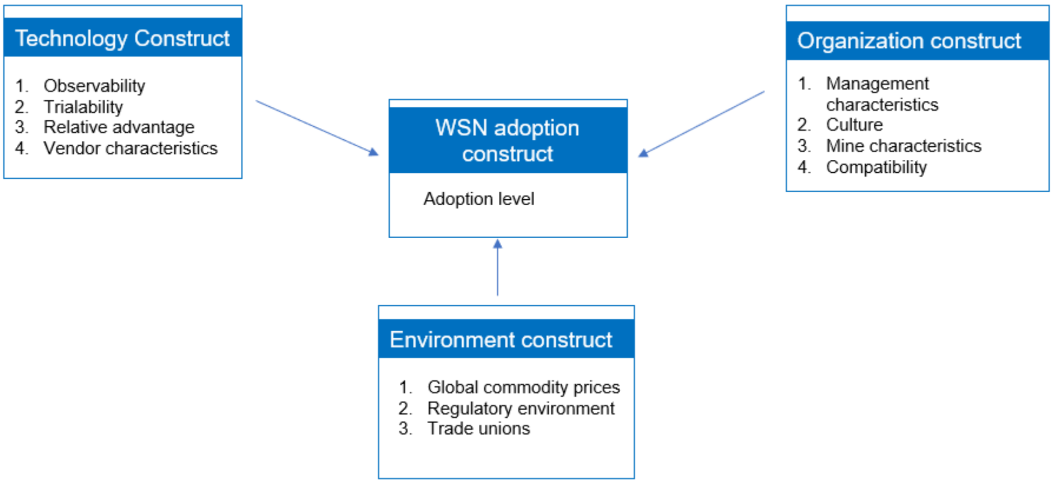

Figure 1. The conceptual model for WSN adoption in mines.

Hypotheses Based on the Research Model

Technology context: The technology context includes characteristics of the technology provider, characteristics of new technology and characteristics of the legacy technology that would be replaced or integrated with Almoawi and Mahmood (2011). The following hypothesis is proposed within this context:

H_1: Technology factors positively influence the adoption of WSN by South African mines.

Organisational context: The organisational context includes factors needed to adopt technology successfully (Pudjianto *et al.*, 2011). As a result, the following hypothesis is put forward:

H_2: Organisational characteristics positively influence the adoption of WSN by South African mines.

Environmental context: Mines are capital-heavy investments typically requiring the mobilisation of foreign investments to set up and sustain operations. Additionally, the minerals and metals produced in South Africa are primarily for the offshore market (Alfers, 2020). As such, many decisions are determined by external factors. The following hypothesis was proposed on this basis:

H_3: The environmental context positively influences the adoption of WSN by South African mines.

Research Design

The research methodology proposed in this explanatory research required collecting and analysing primary cross-sectional data by quantitative method. Measures to be used in the study were adapted from prior technology adoption research based on IDT and TOE frameworks. Measures relevant to mine and management characteristics were adapted from Saint and Gutierrez (2017). Measures for observability, trialability, relative advantage and compatibility were adapted from Saint and Gutierrez (2017). Measures for vendor characteristics were adapted from Curran (2015), Saint and Gutierrez (2017). Measures for global commodity prices were adapted from Curran (2015), and measures for the regulatory environment were adapted from Gruenhagen and Parker (2020). The influence of trade unions was modified from the studies conducted by Cosbey *et al.*, (2016), Crespo Cuaresma *et al.*, (2007). The appendix summarises the measures to be used in this study.

Data collection was conducted using an online survey. A self-administered questionnaire created in Google Forms was used to collect responses (see supplementary file IV). Google Forms was selected over other online survey tools such as Qualtrics because of the ease with which questions could be created, amended, and re-ordered. Additionally, the ease of setting up an informed consent page with an attractive covering photo at the start of the survey was considered an advantage of Google Forms. A 5-point Likert scale with response options ranging from strongly disagree to strongly agree was used instead of a 7- or 9-point scale to give respondents well-defined options to choose from Ireri (2012) and Saunders *et al.,* (2019). The questionnaire was distributed through digital media including email, LinkedIn and WhatsApp for respondents to self-administer. The respondent selection was convenience sampling. A list of contacts was obtained from LinkedIn and Google searches for South African mining industry professionals. This search yielded a list of 226 contacts who were individually contacted and invited to participate in the survey by WhatsApp, e-mail, or LinkedIn message.

RESULTS

Instrument Validation

Validity was assessed using principal-components factor analysis with varimax as the rotation method. Item cross-loadings and factor loading less than .05 were eliminated. Results of composite reliability were greater than .70, which was deemed to be satisfactory according to Keller (2015). Average variance extracted values greater than .5 indicate convergent validity of constructs and the individual variables that they are made up of Keller (2015). All the constructs satisfied the requirements for convergent validity. This study measured reliability through Cronbach's alpha coefficient. Except for the instrument for measuring environmental factors, all the other variables had reliability coefficients greater than the .70 threshold. Therefore, those instruments were reliable measures of their respective variables. Data collected through the instrument for measuring environmental factors should be treated with caution as it cannot be relied on.

All the respondents were found to have roles that would make them encounter WSN technology in one form or the other. Descriptive data was presented for each of the items in the questionnaire focusing on mean and standard deviation of scores. Results for correlation analyses were also presented, showing a mixture of positive and negative correlations and a mix of statistically significant and statistically insignificant correlations. Thereafter, results were presented on the influence of technological, organisational, and environmental factors on the adoption of WSN and WSN based technologies in South African mines. Finally, results of hypothesis testing were presented. In summary, the model developed could predict a small number of variations in the adoption of WSN and WSN based technologies in South African mines and was found to be statistically insignificant.

DISCUSSION

The use of the combined IDT, TOE model was validated, and the hypotheses were confirmed. However, the study's empirical results did not demonstrate an influence that is statistically significant for the measured determinants of adoption of WSN technology by South African mines. Nevertheless, the results of the study were considered to still be of practical significance because in a real-world application, their effect would tend to influence the level of adoption of WSN.

The level of adoption of WSN in South Africa was found to be generally high although the results show that opinions about this varied widely amongst respondents. The specialisation of mine worker knowledge and skills that result from these varied mining methods accounts for the differing viewpoints obtained in the study. The level of adoption observed in this study was in contrast to previous studies e.g. (Williams, 2020, Macfarlane, 2001), which found the level of adoption to be very low, however, responses to the item LVL2: "Our top management have experience implementing WSN from previous projects" was found to be consistent with previous studies.

Technology factors were observed to have a high level of importance amongst factors affecting the level of adoption. Respondents agreed that observability is a determinant of level of adoption, which was consistent with Mahamood *et al.,* (2016). When technology is introduced in mining operations, it is typical that adopters have limited knowledge and experience about the technology, making it necessary to have comparable reference cases where similar technology was successfully implemented. The results for trialability and relative advantage also showed that these were considered to be important factors by respondents, as reported by Job and Mcaree (2017) and Yoon *et al.*, (2020). This is expected because cost, performance and safety advantages and a quick return on investment are amongst the top motivations for the decisions of management when investing in technology (Macfarlane, 2001, Stojanovic *et al.*, 2015). Vendor characteristics were observed to be of high importance and this result was similar to results by Saint and Gutierrez (2017) and Ntsoelengoe (2019), who observed that vendor reputation, ability to support and R&D activity played a significant role in how they were perceived by firms, hence influencing the decision to adopt.

Organisation factors had a markedly high effect on adoption levels with consensus across all items in the instrument. Management characteristics and culture were considered to have generally equal levels of importance as determinants of the level of adoption of WSN and this is in agreement with the findings of Pudjianto *et al.*, (2011), Schmitt *et al.*, (2007), Curran (2015) and Ireri (2012), respectively. This can be explained by the need for top management to sign off on technology purchases. In South African mining, professional networks of engineers facilitate collaboration and sharing knowledge about technology. The results for mine characteristics were consistent with the results of Macfarlane (2001) and Pudjianto *et al.*, (2011) who determined that organisation type and nature of work naturally influenced the types of technology that could be adopted. Compatibility was a major determinant of the level of WSN adoption. This is similar to findings by Yoon *et al.*, (2020) and Ireri (2012).

Environment factors were not ranked as highly by respondents except for the effect of labour unions. This is similar to findings by Kansake *et al.*, (2019); Ntsoelengoe (2019) and Chinwa (2020). Results for government regulations show that these are important determinants of the level of adoption in the South African context. Commodity prices were considered to be of high influence as Ntsoelengoe (2019) observed, because from the point of view of which 'commodity cluster' the mining company is operating in, price levels and operating margins could vary significantly and provide the impetus or act as a barrier to investment in technology.

Hypothesis Test

Observability was observed to have a large negative correlation of statistical significance to the level of adoption of WSN technology. The implication of this finding is that the existence of reference sites in South Africa influences adoption decisions positively.

Readiness Model

Although the results of the regression lack statistical significance, the results suggest that the model has practical significance because the three factors contributed positively to the model. The readiness model can therefore be an effective tool for determining readiness for WSN adoption and, by extension, other forms of smart mining technology.

CONCLUSION

Although a general lack of consensus was observed, the level of adoption of WSN technology by South African mines was revealed to be high. The observed lack of agreement is attributed to the employment of highly distinct mining methods occupying the two opposing extremes of technology adoption. Although, the sample constituents were sufficiently representative by role and knowledge of WSN, the size of the sample impacted the significance of the results. Caution is therefore advised when generalising the findings of the study. Observability was found to have the most significant influence on the level of WSN adoption. The hypotheses were confirmed; however, the readiness model was statistically insignificant in influencing level of adoption.

Recommendations
Technology vendors can use the findings of this research to adopt a new approach as to how they introduce products to the South African market or take the findings as validation for existing approaches. The findings suggest that early adopters of new technology can serve as references to mines interested in the technology, showcasing the benefits of the technology in a typical user environment with the aid of case studies and site visits. Similarly, mine managers can increase adoption levels by using other sites where similar technology is implemented as examples of the potential benefits in their own operations.

Limitation of the Study and Suggestions for Future Research
Limitations of this study include the amount of time available for collecting data from respondents, the size of sample collected and diversity of respondent roles in the mining industry. A longer period devoted to data collection would yield more responses and result in a more significant outcome from the study. Future research can also limit the focus to participants employed directly in mining operations to investigate users' perspectives.

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Change management blueprint for the adoption of modern mining technologies

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As mining modernises, modern technologies, systems and processes will have an impact on people. Change management and the management of change will be required for the implementation of fourth industrial revolution innovations on mines. Hence the objective of this study was to develop and provide an implementable Change Management (CM) Blueprint for the adoption of modern technologies. A collaborative research team was commissioned to develop and pilot (through a case study) a CM Blueprint. The research methodology included focus groups with relevant stakeholders, with an iterative design approach used in the development of the CM Blueprint. The final version of the CM Blueprint included five phases, namely, (1) Prepare, (2) Plan, (3) Pilot, (4) Roll-out, and (5) Support. The CM Blueprint is supported with an online platform, which includes a user-guideline, instructional video and implementation templates.

INTRODUCTION

The project was commissioned by the South African Mining Extraction RDI's (SAMERDI) Successful Application of Technologies Centred Around People (SATCAP) programme of the Mandela Mining Precinct, utilising funding from the Department of Science and Innovation. SATCAP aims to understand the effects, impact and challenges relating to people in the mining modernisation process from all stakeholder perspectives. In 2022, SATCAP focused on the environmental, social, and governance (ESG) agenda, with a specific focus on the *'social'* or *'people in mining'* aspect. The ESG agenda calls for a balance between people, profitability and the environment. The impact of modernisation has brought about the need for mining operations to adapt to various changes. Although various change management models have been incorporated within mining companies, there has remained a lack of a general tool that can assist mining operations with the adoption of modern technologies. Change management is a continuous process that requires understanding from both the technical and people perspective.

The research for this specific SATCAP programme was directed at developing a Change Management (CM) Blueprint for the adoption of modern mining technologies. The researchers used the digital plant inspection sheet as a case study for the piloting of the draft CM Blueprint. The MOSH Leading Practices Adoption System was used as an underpin in the design of the CM Blueprint. A deliverable to the research project was to ensure there is transfer of the CM Blueprint to the project mine. This further contributed to the uptake of the CM Blueprint into mining operational structures.

The aim of this paper is to outline the approach undertaken in the research, the findings in the study, an overview of the CM Blueprint and the pilot study outcomes.

OBJECTIVES AND METHODOLOGY

Research Objectives

The overarching objective of the study was to develop, test and provide an implementable CM Blueprint for the adoption of modern technologies.

The deliverables of the study were outlined as being:

- Research best practice models for effective change management and identify most applicable to the adoption of modern technologies.
- Inclusion of MOSH Leading Practices Adoption System into the CM Blueprint
- Develop and pilot a CM Blueprint that may assist in the adoption of modern technologies within mining.

Research Design

The research design was informed by the context and objectives of the study. A case study was used as the research methodology. The case study undertaken considered the adoption of the digital Plant Inspection sheet used within a gold mining operation. The research design was further supported by utilising focus groups to ensure that an iterative process was followed in the development of the CM Blueprint.

Methodology and Participants

Change management models and theories were researched and compared to serve as a baseline for the development of a draft CM Blueprint that could be used as a foundation to discussions within the various focus groups. The CM Blueprint is underpinned by the MOSH Leading Practices Adoption System. In addition, there were guiding factors that the researchers utilised to ensure that the CM Blueprint is relevant and functional within the mining sector. These guiding factors are outlined as being:

- Alignment to the MOSH Leading Practices Adoption System.
- Aligned to or incorporates the relevant change management models and includes salient aspects of best practice of these change models.
- A model that incorporates both 'Management of Change' and 'Change Management'.
- Agile and applicable for use with other or existing change methodologies currently used within mining companies.
- Aligned to the latest safety, risk and/or legislative requirements.
- Simplified, practical and user-friendly.
- Applicable for the adoption of modern technologies.
- People-centric.
- Scalable to fit the level of change.
- Created for us, by us (co-created with industry specialists and end-users).

An essential facet of SAMERDI and, more specifically of the SATCAP research studies, is the inclusion of stakeholders in the process of research and to ensure that the final deliverables include the perspectives of the various stakeholders. The researchers have ensured that focus groups formed an essential part of the methodology incorporated in the study. The development of the CM Blueprint was an iterative process, with revisions of the CM Blueprint conducted after stakeholder focus groups. The focus groups included the following participants.

- Mining operation delegates and technical representatives from the project mine:
    - Change managers,
    - Technical managers/experts,

    - Information Technology (IT) experts,
    - Mine managers,
    - Safety representatives, and
    - Training and Human Resources.
- Organised labour;
- Subject matter experts; and
- Other relevant stakeholders, i.e. Mine Health and Safety Council and Minerals Council of South Africa members.

The development of the CM Blueprint also included an end-user focused approach. This was to ensure that the CM Blueprint is practical and user-friendly.

Ethics Approval
Ethics approval for this project was granted by the University of Pretoria Ethics Committee (Reference number: EMS150/22). The research complied with all the necessary ethics guidelines and requirements set by the Committee.

RESULTS AND DISCUSSION

Change Management Principles
The first phase of the research study was focused on a review of change management models, processes and principles. The following models were reviewed:

- Kurt Lewin's 3-step change model
- Dr John Kotter's 8-step process for leading change
- Prosci's ADKAR change management model
- The LaMarsh change management model
- The Kaizen change management model
- Eight steps in the management of change
- Edward Deming's Plan-Do-Study-Act (PDSA) cycle
- McKinsey's 7-S model
- Kübler-Ross change curve

Throughout the various stakeholder sessions conducted, it was observed that the principles of the ADKAR model (Prosci, n.d.) corresponds strongly with the CM Blueprint outputs that the team aimed to achieve. The principle of the need for individual change to transpire if organisational change is to be expected, was in part what influenced the development of the CM Blueprint. From the various models reviewed, it was evident that there is the need for continuous stakeholder involvement if success in change management is to be expected. This finding is also relevant to the changes that are brought about in the adoption of technology. The revision of models also highlighted the need for ensuring there is an equilibrium between managing the technical aspects of the change (i.e., new IT systems and infrastructure) and the people facets of the change. This reinforces the need for principles within the ADKAR model (Prosci, n.d.) to have been considered during the development of the CM Blueprint.

The researchers consequently used the principles highlighted above, as well as the guiding factors outlined in the Methodology and Participants section to develop a draft CM Blueprint

Alignment to MOSH
To note importantly, the Minerals Council South Africa indicated that the MOSH Leading Practices Adoption System is a process that identifies leading practices, selects and documents the best of these practices (possibly with refinements) at the operational mine (the source mine), and identifies possible aids and barriers to their adoption at other mines. Technological details of each leading practice, together with detailed leadership behaviour and behavioural communication plans, and procedures for adoption are then compiled by the relevant MOSH Adoption Team into a Leading Practices Adoption

Guide. This guidance is tested at either the first adoption mine, or at a special demonstration mine, and accordingly updated by the MOSH Adoption Team to take account of lessons learned. The MOSH Adoption Team facilitates dissemination of this guidance throughout the industry by presenting details at a Leading Practices Adoption Workshop and by establishing a Community of Practice for Adoption. The MOSH Leading Practices Adoption System fully recognises that, while a technological or procedural solution may have demonstrated effectiveness at one site, success in its adoption at another operation will depend on the key people at that operation – at all levels. Hence the need for change management and the management of change, and the CM Blueprint to enable change leaders on mines to drive change, amongst others, for the adoption of modern technologies.

Thus the CM Blueprint has considered, for application purposes, to support / complement / reinforce /inter-link with the MOSH Leading Practices Adoption System, with the aim being to provide a change management process that may be used for technology related adoption within the mining industry. The result from the study therefore indicated that the CM Blueprint does not replace the MOSH Leading Practices Adoption System but could rather be utilised as a supportive tool for the adoption of leading practices. Further to this, the CM Blueprint can also be used to support adoption of technology initiatives that are not within the MOSH Leading Practices framework.

Critical Success Factors for Adoption Projects
The researchers have identified the following critical success factors for the adoption of new technology projects.

Organisational Digitisation Journey
Work sessions with the focus groups and case study pilot programme highlighted the need of stakeholders to firstly understand how and where the technology initiative fits into the strategy and operational structures. The need for a company-wide digitisation journey roadmap was identified. Participants in the case study pilot programme raised concerns about the maturity of specific operations to adopt technology and the lack of reassurance from a company perspective of an integrated plan.

Progress of other initiatives, and priorities of initiatives, have impacted on the digitisation journey and the contextualisation of efforts need to be understood and be reflected on once the project change team is commissioned. The earlier inclusion of stakeholders also reflected as a critical success factor to the successful implementation of an adoption project.

Participants also experienced that what initially commenced as a beneficial project rapidly turned into a burden, influencing commitment negatively going forward. Reassurance is required from the larger organisation as to the intent of the specific project and the expected behaviour. Technology is an accelerator, where the women in mining strategic imperative should benefit from this planning.

Reflection on Previous Initiatives
Technology adoption projects tend to lack a review process in a consistent manner to follow a Plan, Do, Check, Act (PDCA) cycle towards quality improvement. Projects need to make provision to share learnings with other projects before new initiatives commence. The industry must share learnings and prevent repetitive failures. Industry forums could capacitate the journey and increase the levels of participation in these opportunities. Reflection minimises challenges in the future and keeps the organisation accountable for the reasons behind adoption projects failing.

Current versus Future Resources
Previous initiatives impact on the perceived probability of success and set the tone for determination of future success. Before the change process journey can commence, the resource plan needs to be reviewed as there is a difference between 'what' we do currently versus 'what we want and should do'. The current change management approaches and methodologies were found to be critical during this phase to ensure cultural alignment.

Identification of Technology Readiness

During the various site visits and focus groups it was identified that there is the need for mining operations to identify whether there is a level of readiness for the adoption of a new technology. The research team developed the following template (Table I) to assist operations in the assessment of readiness levels for technology adoption.

Table I. Technology readiness assessment

Change Management Blueprint - TECHNOLOGY READINESS					
Part I - Description and status of the technology					
What is the name of the technology?					
What is the purpose of the technology development / modification?					
Which section or process of mining activities does the new technology impact?					
What is the current state or what problem will this technology try to solve within the mining processes?					
What is the current status of the technology, based on the TRL assessment below?					
Part II - Technology Readiness Assessment					
Technology Readiness Level (TRL) Assessment:					
Phase	*TRL*	*Description*	*Questions to Assess Technology Readiness*	YES	NO
Research	1	Basic principles observed and reported	Are there rough calculations, basic principles or paper studies to support the concept?		
	2	Technology concept and/or application formulated	Has the technology concept and/or application been formulated?		
	3	Analytical and experimental critical function and/or characteristic proof of concept	Is there a proof of concept? (e.g., validation through modelling and simulations, feasibility of technology demonstrated)		
Development	4	Component and/or breadboard validation in laboratory environment	Has the performance of the individual components of the technology been tested in a small-scale environment to determine if they will work together?		
	5	System/subsystem model or prototype demonstration in a laboratory environment	Has the performance of the components of the technology been tested in a relevant (large-scale) environment?		
	6	System/subsystem model or prototype demonstration in a relevant environment	Has the system/subsystem prototype been tested in a simulated operational environment?		
Deployment	7	System prototype demonstration in an operational environment	Has the fully integrated prototype been tested in an operational environment?		
	8	Actual system completed and qualified through test and demonstration	Has the technology been successfully technically developed, tested/demonstrated and evaluated?		
	9	Actual system proven through successful mission operations	Has the technology been successfully proven through use in actual operations?		

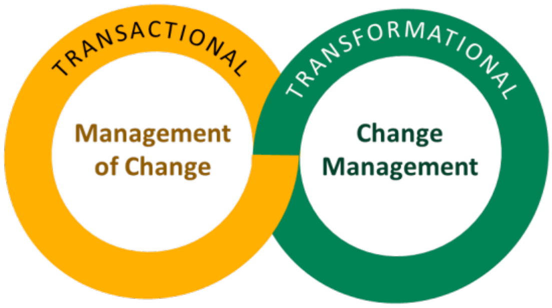
Adapted from BMGF (2012)

The technology readiness assessment is one of the success factors that is usually overlooked by operations. The findings indicated that there is often the willingness to introduce new technologies but that operations do not necessarily have the structures, knowledge and practical application experience.

CASE STUDY PRACTICAL APPLICATION

The research team applied the CM Blueprint to a plant inspection sheet of a gold commodity mining operation as a case study for the research. The digital plant inspection sheet is utilised as a method to identify potential hazards and risks surrounding specific plant and machinery. It ensures that operations are compliant with Safety, Health and Environment regulations and legislation governed by the Department of Mineral Resources and Energy. The aim of the technology adoption project on the mine operation was the transfer of the plant inspection sheet to a digital platform, and hence a change management process was essential, to ensure adoption of the technology.

It was identified during the research that there is a need for persons applying the CM Blueprint to firstly understand that concepts of 'change management' versus the 'management of change'. The researchers thus included a description of the terms (see Figure 1) as an introduction to the application of the CM Blueprint.



Management of Change (MOC) deals with the **technical side of change** and how to avoid or minimise risks arising from changes in equipment, process, and handling of chemicals.

Change Management (CM) deals with the **people side of change** and the main goal is to effectively guide people to transition from a past/present state to a future desired state. The challenge for any organisation is to smoothly perform change management during MOC. It's the role of management to influence people's behaviour in reaction to technical changes.

Figure 1. Transactional vs transformational.

During the case study, the researchers identified the following considerations /questions that need to be posed to the technology adoption project team prior to the use of the CM Blueprint:

- Is the technology aligned to the legislative and regulatory requirements?
- Does the mining operation have the necessary access to hardware and software required for project implementation?
- Does the mining operation have the necessary technical expertise for the adoption process?
- Will the mining operation have the necessary infrastructure in place to support the project?
- Has training been done for users of the new technology?
- Do the users have the require skill sets to effectively use the technology?

The above listed questions, although not exhaustive, outline the need for readiness assessments to be undertaken prior to any technology adoption project. The CM Blueprint application assisted in identifying the potential inhibitors to the success of the technology adoption project. The research team assisted the mine operation in conducting a 'probability of success' exercise that determined the necessary pre-work to be conducted by the mine operation. The applied CM Blueprint further identified the gaps within the stakeholder map of the persons that must be included in the technology adoption project.

During the 'project team and role-player identification' aspect of the CM Blueprint application, it was evident that the CM Blueprint assists in ensuring that relevant stakeholders are included earlier in the adoption process. The early engagement and inclusion of stakeholders was previously identified as a critical success factor to the change process. This confirmed the need for the CM Blueprint to incorporate both the technical and 'people-centric' aspects in the adoption of new technologies.

In addition, the case study allowed for identification that certain of the phases and sub-tasks in the CM Blueprint required clearer explanations and examples. This was included in the final version of the CM Blueprint.

Observations and inputs received from participants during the case study pilot programme indicated that the CM Blueprint should be developed around the following headings: *Prepare, Plan, Pilot, Roll-Out and Support*. The final version of the CM Blueprint is illustrated in Figure 2, with the subsequent headings and sub-task per phase.

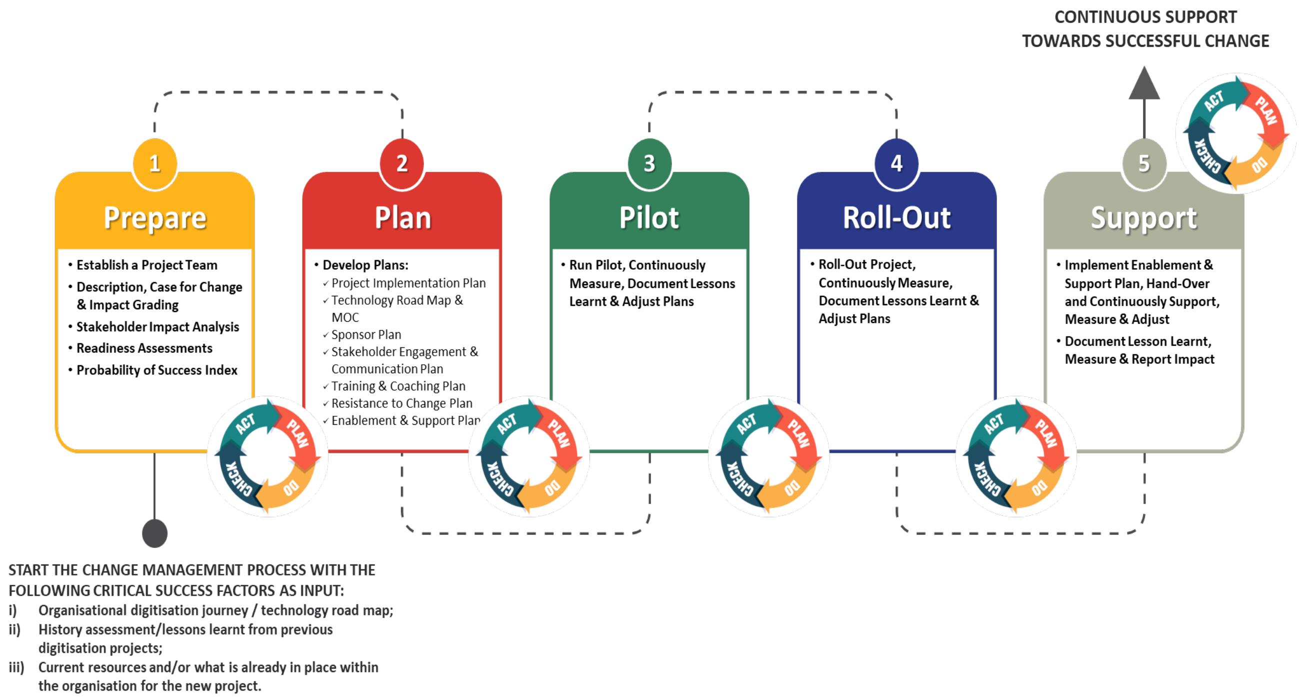


Figure 2. Change Management Blueprint phases.

The CM Blueprint and feedback received during the case study practical application is discussed in the following sub-sections.

Phase 1: Prepare

- Concerns were raised that the current practices were not working during paper-based systems. The need to have process flows and process charts in place before moving to a technology-based solution was identified.
- Observations were made that the continuous changes in paperwork (e.g. adapting paperwork to align to legislative requirements in logbooks/inspection sheets) move any digitisation/technology process backwards.
- Readiness of stakeholders is not incorporated in current practices (i.e. progression vs comfort zones). There is thus a need for inclusion of a 'people-readiness' section.
- Inclusiveness of stakeholders is critical within the preparation phase as there is a tendency to exclude critical support systems like IT, procurement and training.
- Expose senior leaders to what is happening to accelerate technology readiness of these levels.

Sub Task 1: Establish the project team

- The team should include technical support early as it is clear that the impact should be understood and planned for; technical adjustments are normally time-consuming.
- The reinforcement manager is the operation leader, and it was found that they are normally on-boarded too late in a process.
- Leadership behaviour is of utmost importance (express – model – reinforce)
- It is essential to establish a strong project team triangle (sponsor, change manager, project management), the subject matter experts, reinforcement manager and IT/Technology support.

Sub Task 2: Case for change and impact grading

- Value-added time vs non-value-added time should become one of the key drivers of any modernisation journey.
- A clear and shared understanding of the change and business case behind implementation should be made.

Sub Task 3: Stakeholder impact analysis

- Identifying the right stakeholders at the right times (focusing on services to the core business).
- Consistent and continuous engagement during technology planning and adoption, and not only when your stakeholders' approval is required. Stakeholder engagement is a relationship and not an event.
- Feedback to stakeholders once they were engaged.
- Life of mine does influence the aptitude for technology and modernisation acceptance.
- Purpose of stakeholders' engagement should be values-driven (research initiatives create expectations which should be managed).

Sub-Task 4: Readiness analysis

- Technology readiness for adoption remains an inhibitor.
- Maturity for the adoption of technology levels within the South African mining industry differs substantially.

Sub Task 5: Probability of success index

- Failure is mostly due to a lack of proper sponsorship in the business.
- Lack of adequate resourcing.
- Budget restrictions are often imposed as modernisation initiatives are expensive and the first to be halted in difficult economic times.

Phase 2: Plan

- In general, the industry struggles with adoption as people in mining are perceived as being stubborn, set in their ways, and fear failure.
- Concerns about how safe it is for this context and possible loss of jobs are typical questions to be addressed during change management.
- Not answering the 'why' of new technology and how people will be affected, are overlooked in the past and has an impact on the present.
- The state of mind on readiness for technology will determine the budget allocation and amount of time allocated for change management initiatives.
- Good paperwork that requires less people work is a motivation to ensure the planning phase is done correctly.

Phase 3: Pilot

- There are operations that have not utilised this phase effectively in the past. Instructions were received and compliance required instead of Phase 2 being utilised to inform Phase 3 and ensure that operational employees are aware of the change and the reasoning behind the change.
- A lack of accountability during the pilot phase highlighted the need for acceptance and ownership to be reinforced during this phase.
- The honest question needs to be asked whether this is practical, and are we as an operation able to implement further? The pilot phase outlines the need for reviewing the business case and understanding the realities of the change.
- The utilisation of an activity such as 'a day in the life of' (DILO) contributes greatly to identifying the needs of the target group and driving for higher acceptance in the target group.
- Successful and unsuccessful pilot programmes highlight the lessons learnt and increase the probability of success in the adoption of new technology projects.

Phase 4: Roll-out

The digital tool could not be rolled out to all operations and thus no clear evidence is received from this phase. Participants however reiterated the importance of communication and the necessity for continuous project sponsor support during this phase.

Phase 5: Support

Participants indicated that they have learnt in the past that:

- Data analytics and impact - usage and storage of data to make forecasts and trends is important.
- Measuring of impact should become institutionalised.

The feedback received during the case study pilot programme was included in the final version of the CM Blueprint.

Considerations Prior to Implementation of CM Blueprint

It was noted in the case study pilot programme that there are certain considerations prior to implementation of the CM Blueprint. There is a need for mine operations to have the necessary training, environmental considerations, technology support infrastructures and organisational support structures in place prior to roll out of technology adoption projects. It is around the conduciveness of the environment for the technology being implemented. Certain of the considerations that need to be included prior to the implementation of the CM Blueprint are outlined in Table II.

Table II. Considerations prior to implementation

Considerations	Description
Skills & Training on technology	The mine operation needs to consider the levels of skills needed, training /knowledge that the relevant role-players have with regards to the specific technology, and if these are lacking or limited, put in place development plans to address these.
Literacy levels	Consideration must be provided to the literacy levels of the users in the specific technology. More broadly there is also the need to understand the digital literacy of the project team and users of the technology.
IT infrastructure and systems	From the pilot undertaken, it was noted that sites may be willing to undertake the adoption of new technologies but that there may not be sufficient IT infrastructure in both hardware and software. Mine operations thus need to consider and investigate the technology support structures that are required for adoption of the new technology.
Environmental considerations / working conditions	This is concerned with understanding the environment in which the technology will operate. Considerations such as the physical environment needs to be assessed (i.e. Narrow, low stopes, tight, dusty, hot and wet working conditions. etc.). Inputting of data may be cumbersome and clumsy and if PPE is to be removed, such may create unsafe working conditions etc.
Unions and DMRE/stakeholder inclusion	Agreement, buy-in, inclusion and support are needed from all stakeholders, including unions, regulators and employees. Health and safety risks and concerns should be addressed. Lack of stakeholder engagement leads to resistance to the acceptance of the change. Demands for the increase of job levels within operational hierarchies and pay for new skills/ higher skilled jobs (current job profiles do not include use of digital devices and digital literacy skills). Individual employees are also concerned that technology will track and monitor their actions with negative consequences. Compliance and regulatory issues need agreement prior to further engagement.
One-size fits all approach	Mine conditions, environments and contexts vary, so mine operations cannot use the same product/system on every mine – even shafts have different needs.

The considerations in Table II are not an exhaustive list and the recommendation is made that each operation develops their own list of considerations prior to the technology adoption project.

TRANSFER TO INDUSTRY

The objectives of the research project included the transfer of the CM Blueprint to industry. The project team utilised the partner mine as a departure point for transferring the CM Blueprint to industry. The mine partner was involved with the development and pilot of the CM Blueprint. Post-development of the CM Blueprint, a training session was also undertaken with the mining partner. The session included the various stakeholders involved in the adoption of the digital plant inspection sheet technology for the mining operation. These stakeholders were identified as per Phase 1 of the CM Blueprint.

In addition to this, there has been engagement with MOSH Leading Practices Adoption System team representatives. The project team also presented the CM Blueprint to the Behavioural Interest Group forum. The research team is further interacting with industry through industry forums for uptake.

A feature that may increase the transfer to industry is the user-guideline and tutorial video that supports the CM Blueprint and enables use thereof.

User-Guideline

The CM Blueprint is accompanied by a user-guideline and instructional video. The user-guideline outlines how the CM Blueprint should be implemented by the user. The user-guideline includes a description of the templates and the outline thereof. Figure 3 illustrates the various sections of the user-guideline.

Figure 3. User-guideline sections.

The user-guideline outlines each step of the CM Blueprint and how the tool should be implemented. The user-guideline also includes the purpose description of each phase, the purpose of each sub-task, and examples supporting each sub-task.

Supportive Tools

The CM Blueprint was developed with supportive tools that will enable the user to implement the CM Blueprint successfully at their operation. Figure 4 illustrates a screen capture of the online portal that is accessible on the Mandela Mining Precinct.

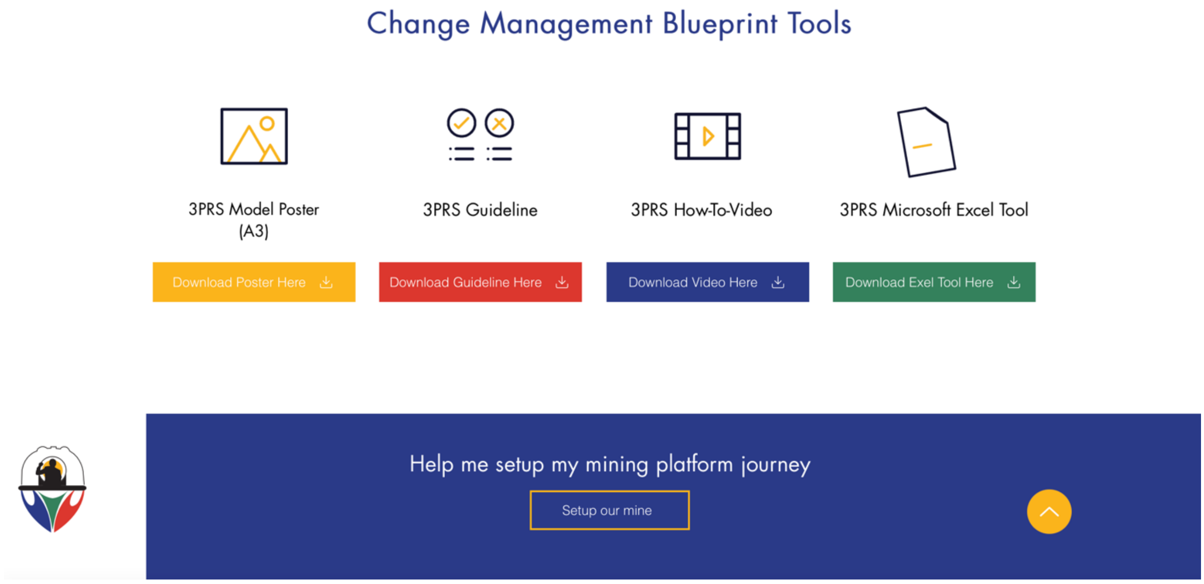


Figure 4. Online platform.

The online platform includes a model poster of the CM Blueprint, the user-guideline, an instructional video and the CM Blueprint tool. The CM Blueprint tool is available in an Excel file format, which ensures that any user can download the tool without requiring specific software.

CONCLUSIONS

Well-considered design criteria (i.e. guiding factors) were used in the development of the CM Blueprint. Best practice models and salient aspects were taken into consideration. The guiding factors and inputs from key stakeholders have underpinned the CM Blueprint development process. The CM Blueprint may be used either as a full change management process or to supplement an existing change management process that a mining operation already utilises. Therefore, any of the phases, sub-tasks within the phases, and/or templates may be replaced/skipped depending on the needs from the specific change initiative. The CM Blueprint can be utilised to support the implementation of MOSH Leading Practices; it therefore does not replace the MOSH Leading Practices Adoption System, but rather serves as a support thereto.

The study findings indicated that there is a need to understand change from both a technical and a people perspective. The implementation of the CM Blueprint ensures that there is consistent balance between the people (change management) and technical (management of change) perspectives in the adoption of new technologies. The study also indicated the need for identifying the people, technology and change readiness of an operation prior to the adoption of a new technology project.

ACKNOWLEDGEMENTS

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Community and SMME training-needs assessment survey tool

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A collaborative research team was commissioned to develop and pilot a training-needs assessment tool (the survey tool) for potential use by gold and platinum mining companies within their local communities. The research design was explanatory in nature with a design-thinking approach incorporated into the tool development. For the tool development, a literature review was undertaken to obtain insights into national-, and international best practice tools. The draft survey tool was piloted with mining partners, local community members and small, medium and micro enterprises (SMMEs) to understand the usability, functionality, language and structure. It was determined that the survey tool allows for grasping an understanding of both the current and future skill needs of communities and SMMEs. During the pilot, it was emphasised that on-going stakeholder engagement and inclusion are critical. The inclusive identification of skills needs within local communities may ensure that there is greater alignment between the expectations of mining operations and the skill development needs of communities.

INTRODUCTION

The project was commissioned by the South African Mining Extraction, Research, Development and Innovation (SAMERDI) Successful Application of Technology Centred Around People (SATCAP) programme of the Mandela Mining Precinct, utilising funding from the Department of Science and Innovation. SATCAP aims to understand the effects, impact and challenges relating to people in the mining modernisation process from all stakeholder perspectives. In 2022, SATCAP focused on the environmental, social, and governance (ESG) agenda, with a specific focus on the *'social'* or *'people in mining'* aspect. The ESG agenda calls for a balance between people, profitability and the environment. Addressing current social needs, including skills needs which support the legacy that mining operations leave behind, post-mining, is critical for self-sustainability of local mining communities. Training for current skills and future skills that equip local mining communities in being prepared for a more sustainable future has thus required a deliberate focus on understanding such skills needs through crafting and piloting of an assessment tool.

The research for SATCAP was aimed at developing a training-needs assessment survey tool (the 'survey tool') focused on communities and small, medium, and micro enterprises (SMMEs) for potential use and implementation by Gold and Platinum Group Metals mines. As mines close, the impact thereof on the sustainability of communities post-closure needs foresight. Mines want to create more self-sufficient communities that are sustainable post-mine closure. SMMEs and community training needs must be identified to ensure that mines understand the needs of communities and that these are addressed in future training initiatives. This will enable economic growth and transformation, innovation, entrepreneurship, and job creation, amongst others, which can support post mining communities to endure and potentially prosper.

To address the above areas the objectives of the study were:

- To uncover practices from industry (locally and globally) as related to community and SMME training-needs assessment.
- To provide a tool that is piloted to enable securing of SMME and community current and future training needs.

The aim of this paper is to outline the approach to conducting community and SMME training-needs assessment through the use of a digital tool.

METHODOLOGY

Research Design

The research design was informed by the context and objectives of the study. Within these parameters, it was decided to incorporate an explanatory design, with a human-centred design thinking approach in the tool development. The use of an explanatory design provided the research team with the platform to investigate innovative solutions to the research problem. Furthermore, the explanatory design also provides the opportunity to define key concepts (i.e., alternative economies), explain how the concepts are used in practice, and why these concepts are applicable to the design and construct of the proposed solution.

Approach and Participants

For the initial draft tool development, a literature review was undertaken to obtain insights into national and international best practices of community assessment tools. A gap analysis was concluded, and the tool concept was designed and developed. Insights into the tool development were gathered through focus groups with research partners, subject matter experts (i.e., learning and skills development, information, and communications technology), and mining partners who facilitated input from community engagement, stakeholder relations and learning and development practitioners. The focus groups were conducted at both Gold and Platinum Group Metal operations in Gauteng and Free State provinces.

The initial tool was piloted with mining partners and local community members to understand its usability, functionality, language and structure. The pilot programme was undertaken through a focus group format with the practical application of the survey tool being tested. Four focus groups with a total of 68 participants (distributed between the various focus groups) participated in two pilot studies conducted at two mining operations in Gauteng to assess the practical application of the survey tool. The participants were comprised of the following representatives:

- Business forums, networks, community-based organisations, non-governmental organisation;
- Existing SMMEs and local suppliers;
- Community members;
- Community members who are potential SMMEs and local suppliers;
- SMMEs in the incubator programme;
- Potential industrialists and black industrialists; and
- Subject matter experts.

Onsite pilot testing for the tool was conducted with partner mines in September and October 2022. The physical pilot testing sessions were scheduled for three hours, and included the following three phases:

- Orientation phase – project introduction, question and answer session, and request for informed consent;
- Tool run-through – facilitated progression through the tool content on laptops, smartphones, or computers; and
- Tool validation with participants – focus group discussions to gain verbal feedback on the tool.

Data Analysis
The data analysis is summarised in three phases with a human-centred design thinking approach adopted. These phases are outlined as follows:

1. **Understanding and synthesising data:** Data was collected through literature reviews, focus groups and pilot testing. By combining both primary and secondary sources of qualitative and quantitative data, the research team was able to evaluate existing training and skills needs assessment tools across varying industries and geographical locations.

2. **Ideation and analysis:** During the ideation phase, engagements were held with mining, technical and research partners to understand the needs of the mining sector and inform the features of the customised training and skills needs assessment application. Structured focus groups were held with mining partners and external stakeholders to understand how to structure a needs assessment instrument that allows the mines to collect the information they need and the users to provide the mines with timeous relevant information to enable evidence-based decision making. Ideas and approaches in these sessions were then tested with research and technical partners through a series of semi-structured collaborative working sessions. From these engagements, the team analysed findings under specific themes and developed a draft training and skills needs survey for community members and SMMEs. The draft survey tool content questions were then validated through additional feedback sessions with internal team members, mine representatives [Heads of Departments of Learning and Development/Skills Development, Social Performance, and Information Technology (IT)] and technical experts (information, communication, and technology subject-matter experts).

3. **Testing, iteration, and refinement:** Using an iterative process, an initial version of the survey tool was developed in collaboration with technical partners. Through a series of meetings and negotiations with mining partners, a physical pilot of the survey tool was conducted with 68 participants comprising community members and SMMEs. The survey tool was refined in accordance with insights obtained from participant observations on the day of the pilot and a thematic analysis of participants' responses to a usability study documenting their experiences using the survey tool.

Ethics Approval
Ethics approval for this project was granted by the University of Pretoria Ethics Committee (Reference number: EMS148/22). The research complied with all the necessary ethics guidelines and requirements set by the Committee.

RESULTS AND DISCUSSION

Key findings derived from desktop research, a literature review, stakeholder engagements and focus groups, revealed that the tool should be able to assist the mining operations to assess the training and skills needs of the local community and SMMEs surrounding mining operations. It was envisaged that the tool would allow for mines to investigate the training and skills needs in the communities to support current and future training needs, as well as training needs as the community progresses towards a post-mining economy.

Insights from Stakeholder Engagement
The key insights from the data gathering process via focus groups and stakeholder engagement sessions are presented in Table I.

Table I. Insights from stakeholder engagement

Organisation	Insight
Governing/ Regulatory body	• Mining companies face local procurement constraints, as SMMEs are not adequately ready to tender for work with the mines. • Issues reside in finding a meaningful way to engage with SMMEs to present opportunities that are available now versus those that are available in the future. • Soft skills are an integral part of the modernisation of mines.
Mining partners	• Current skillsets of communities and SMMEs do not meet the needs of new economies; hence the tool should provide data on transferable skills of communities and SMMEs in different sectors. • Tool should place less emphasis on training and skills needs as mining company has a good understanding of this area. • Tool should be able to capture SMMEs that operate in alternative economies. • Tool should capture the evolving training and skills requirements of communities and SMMEs. • There should be an emphasis on separating opportunities for community members versus opportunities for SMMEs. • The tool should categorise SMMEs according to experience and size. • Tool should include a disclaimer regarding expectations and highlight what the mine is able to manage in terms of training support for communities and SMMEs. • Differentiated training is required for SMMEs, as needs are not homogenous. • Training on compliance and health and safety is required for SMMEs providing services to the mines. • The women business chamber has developed a model to profile businesses, in addition to conducting interviews to understand the needs of women entrepreneurs. • Business management skills continue to be an underlying problem for SMMEs.
Implementation partners	• Agriculture is an important sector in relation to new industries that are labour-intensive with the capabilities to absorb unskilled and semi-skilled workers. • Mining communities inherently possess underutilised skills, this needs to be channelled in a meaningful manner towards new industries. • Primary gap exists in intelligence mechanisms in the mining industry to access data related to SMMEs in the area. • Tool overlaps with work undertaken by other community organisations. • Content questions need to also be able to capture the current skills base of communities and SMMEs, this should not purely be forward looking - this will provide a bigger picture of the types of businesses that exists.
Academic partners	• The content of the tool speaks to the training needs of communities and SMMEs (this was addressed in subsequent iterations); and • Minor changes to be made with structure, format, and grammar. The tool needs to be more focused on the levels of literacy for easier engagement.
Technical partners	• Tool must be a web-based tool and cannot be a catch-all application. • Accessibility (to the internet and a device) needs to be the key aspect to be taken into consideration. • Language limitation regarding open text inputs. • Mines are to provide connectivity and internet infrastructure to their communities/SMMEs/Non-Government Organisations. • Application tool to be open source – must be accessible by all community and SMME members. • Tool content will be in English.
Social Performance and Supply Chain Development teams	• At present, the gold mining partners have conducted external engagements where a tool known as 'Ulwazi' was undergoing piloting. • Need to consider political risk which includes aspects such as tribalism. • In terms of receiving input and validation into the types of alternative economies present within and around the mine, those alternative economies included regenerative agriculture, agro-processing, renewable energy-carbon

	reduction, mine waste beneficiation, and light manufacturing inclusive of the District Development Model. Mine is also donating land for future use cases. • Current community and SMME skillsets do not meet the needs of future economies. • Enterprise and Supplier Development Programmes exists that support a small number of SMMEs to venture into different industries.
Stakeholder Relations and Supply Chain Development teams	• In terms of tools utilised within the mine, two tools were mentioned namely Lephora, and a gap analysis tool mainly used for enterprise and supplier development purposes. • In terms of receiving input and validation into the types of alternative economies present within and around the mine, those alternative economies included regenerative agriculture, recycling, textiles, e-waste, agro-processing, renewable energy-carbon reduction, mine waste beneficiation, light manufacturing inclusive of District Development Model, and information and communication technology. • Types of SMMEs approaching the mine interested in operating in agro-processing, renewable energy, textiles, and producing chicken feed. • Tool should account for future skills and help mine ascertain needs of SMMEs. • Engagement with the community has been challenging.
Community engagement practitioners/ SMME	• SMMEs lack key critical skills such as digital literacy, ethical practices, and health and safety training (future training should address this). • The main types of services offered by SMMES in mining communities are in the services sector. • Mining companies offer Enterprise and Supplier Development programmes; however, entrepreneurs face opportunity costs to access these services. • Main challenges of SMMEs is suitability and their reliability in producing quality services - training should therefore focus on this aspect. • Agriculture is an important sector in thinking about new industries that are labour-intensive with the capabilities to absorb unskilled and semi-skilled workers. • Mining communities inherently possess underutilised skills, this needs to be channelled meaningfully towards new industries. • Primary gap exists in intelligence mechanisms in the mining industry to access data related to SMMEs in the area. • Tool overlaps with work undertaken by other community engagement companies. • Content questions need to also be able to capture the current skills base of communities and SMMEs, this should not purely be forward looking - it will provide a picture of the types of businesses that exist. This was addressed in subsequent iterations.

(*(Source: Likaku* et al.*, 2023)*

From the focus group discussions with mine partners, community representatives, and SMME representatives, the commonly shared insights can be summarised as follows:

- The current skillset of communities and SMMEs does not meet the needs of the new economies and the tool should be able to surface transferable skills in different sectors and areas of interest of SMMEs and communities.
- The tool should place less emphasis on training and skills needs within the mining sector, as mining companies already have a suitable understanding of this specific area. There was a need to expand beyond the borders of mining operational requirements.
- The tool should be able to capture current and future training needs to equip SMMEs that may want to operate in alternative economies.
- The community and SMMEs' training and skills needs are evolving, and the tool should be able to capture the emerging and priority training needs in real time.
- The tool should categorise SMMEs according to experience.
- The tool should include a disclaimer regarding expectations and highlighting what the mine is able to manage to facilitate and support training in mining communities.

Tool Development
The survey tool was created with inputs from the research team and development team with feedback during the co-creation sessions. These sessions were facilitated via a design thinking approach and included an iterative process for design, development and testing. Informational resources related to styles and modes of learning, in addition to skills needed for alternative economies and business-related training, are included in the survey tool.

The features listed below are included in the tool:

(i) Survey – specific to community members, SMMEs and mine employees;
(ii) Resource library; and
(iii) Notice board.

Through a series of four iterations, different elements of the tool were built sequentially:

- Core survey for end users with key questions and response options;
- Information resources and glossary/terminology examples;
- Back-end administrator and super administrator functionality for administering the survey, managing users, managing the data sets and compilation of analytic reports; and
- Dashboard with aggregator analytic reports for core questions and robot summary reports for managers to view.

The survey tool is designed in a manner that all participants (i.e., community, SMME, mine employee) are able to answer more than one section. For example, mine employees are able to complete the community section if they reside within the community. A respondent can be both a community member as well as an SMME, thus both community and SMME sections of the assessment would apply.

The survey tool consists of the following features:

- 43 questions that encompass the key focus areas of the community and SMME skills needs;
- Questions consist of multiple-choice, checkboxes, drop-downs, and open texts; and
- The resource library serves as a repository of useful information on alternative economies and skills needs.

Pilot
The tool was piloted with mining partners and local community members to understand its usability, functionality, language and structure. It was determined that the tool allows for grasping an understanding of both current and future skills needs of communities and SMMEs. Continuous stakeholder engagement was identified as a critical success factor in the implementation of the survey tool. There is greater alignment between the expectations of mining operations and the skills development needs of communities if there is shared activity around the identification of training needs in the community.

Feedback from the on-site pilot with SMME and community representatives centred around the usability, functionality, language and structure of the survey tool is detailed below:

- *Language and syntax*: The inputs from the SMMEs, research and mine partners ensured that the questions and answer options were not potentially offensive to the target audience; and
- *Usability*: The inputs from the mine partners and SMMEs helped to address any issues of usability and functionality.

During the pilot, the survey tool reporting process of the tool was tested. Functionality design within the tool allows for survey data to be captured, analysed and presented in aggregator reports which enable mining partners to have real time data driven insights to base their decision making on training priority areas. Figure 1 illustrates the percentage of community respondents that have acquired various skills through training. This may indicate to the respective mine whether the communities received training of any kind and which skills they acquired. This information can inform the type of skills that require improvement, should the respective mine choose to provide such training support.

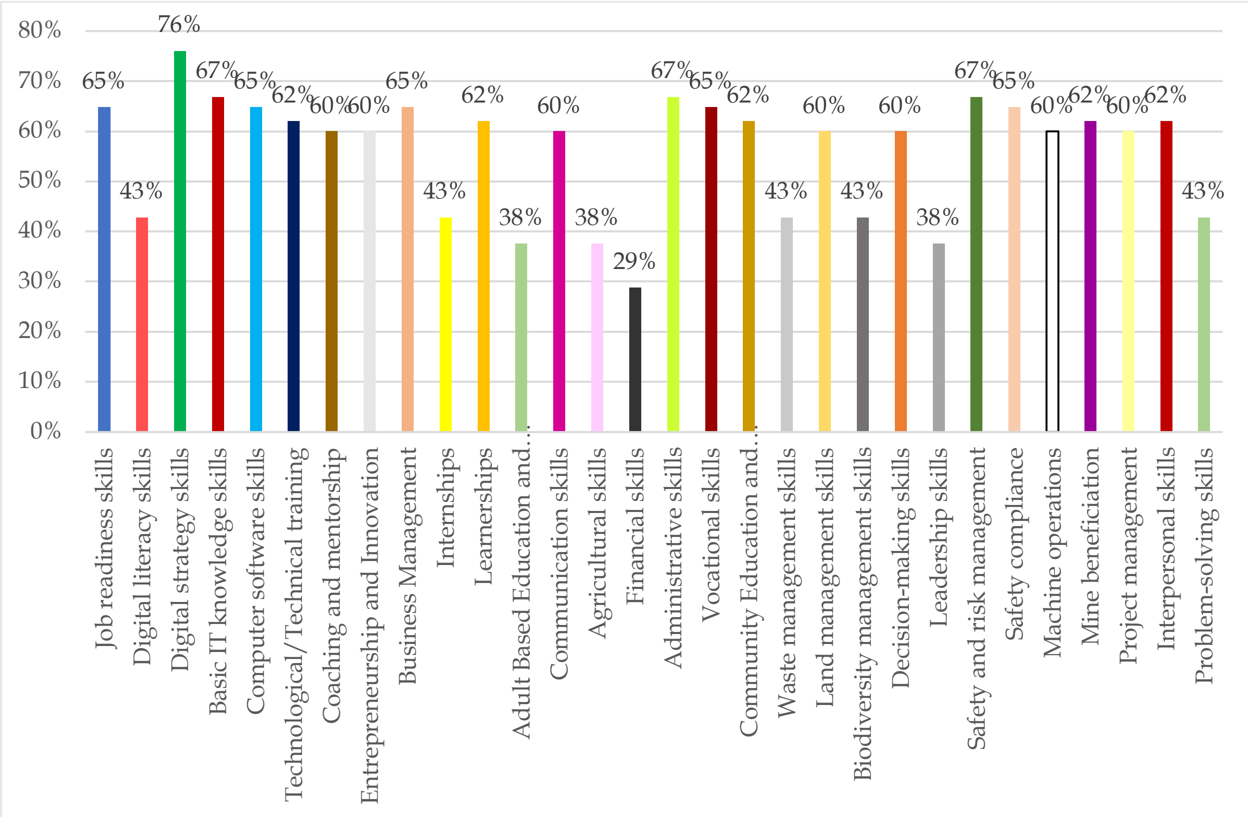


Figure 1. Report output on current skills training of communities and SMMEs.

The pilot was also used to test whether the survey tool can identify the alternative economies applicable and prioritised within the local community. Figure 2 outlines the findings from the pilot with regards to the interest of communities in alternative economies.

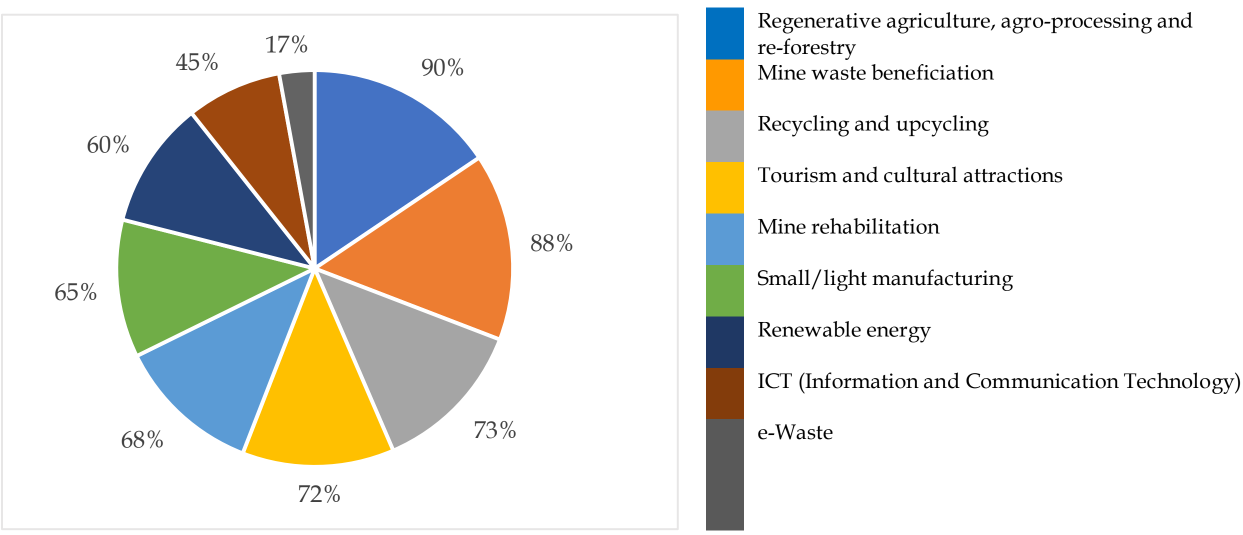


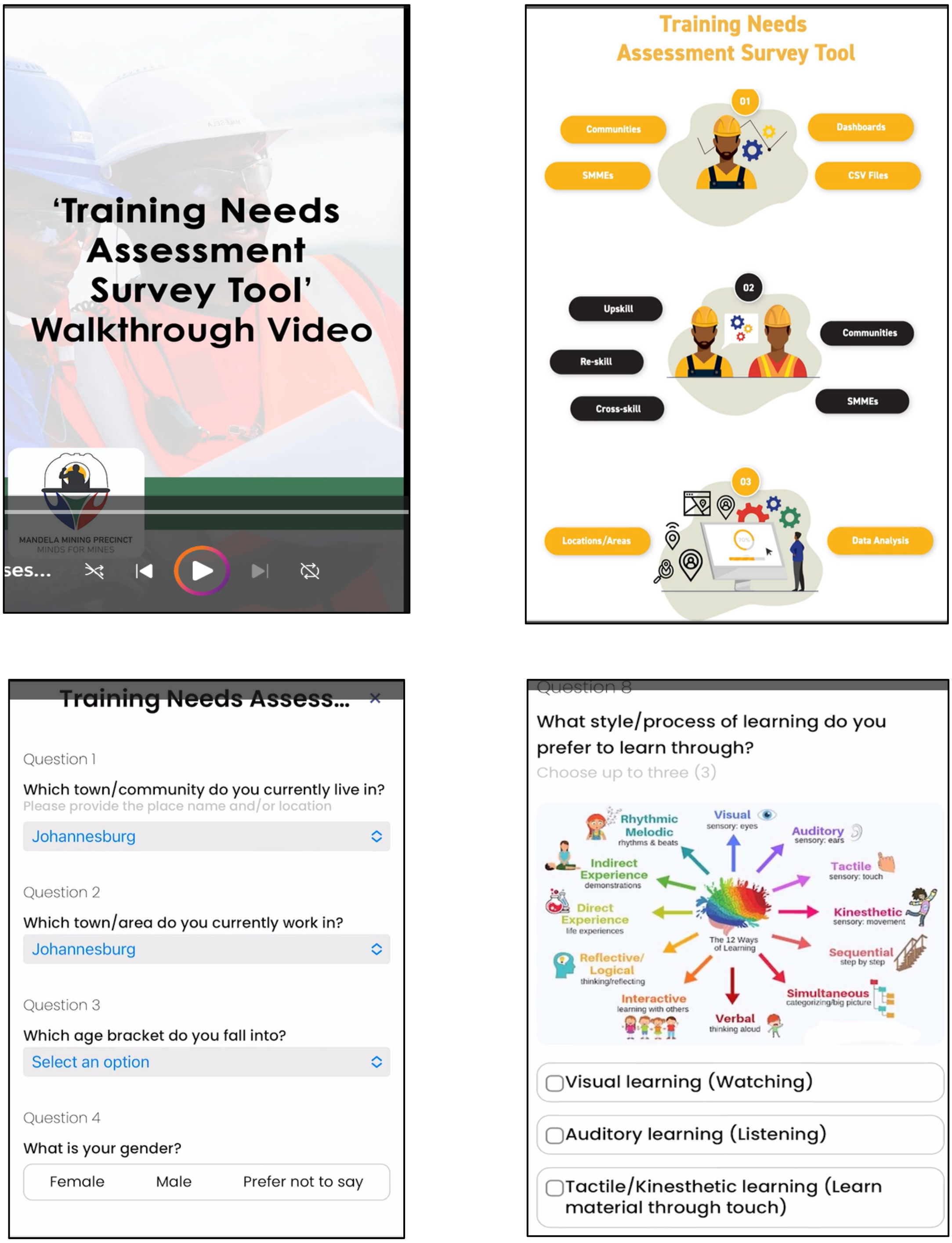
Figure 2. Interest of local communities in alternative economies.

It needs to be noted that the findings outlined in Figure 2 were part of a pilot and these findings cannot be extrapolated to the broader sector. There would be a need for a mining operation to utilise the survey tool within their specific geographical area in a specific mining location and surrounding community to ensure findings are relevant to their operation. The pilot programme did identify that the reporting is relevant to the objectives of the study and identifies the interests of local community members regarding alternative economies. This interest can provide the mining operation with guidance on the focus areas of local economic development through the inclusion of community members and SMMEs into the relevant value chain of the operation.

Transfer to Industry
The research team developed a practical user-guide to ensure there is a transfer of the survey tool to the industry. The user-guide provides a process on how the system reports should be interpreted for decision-making by the manager of the respective mine. Figure 3 illustrates examples of the user-guide. The user guide also has the instructions to embed the tool in the mine's information management environment, and instructions for users and administrators.

Figure 3. User-guide for survey tool example.

An instructional video has also been created in addition to the user-guide. This further provides guidance to the user on how the survey tool operates. Figure 4 illustrates a screen capture from the system.



Figures 4a-d. User tutorial video and tool features.

The tool is designed in open-source code and is a stand-alone web-based application accessible by the user on a smartphone, laptop, or tablet. As hosting of the application is in the mine's information management environment, all data collected by the mine will be stored in the mine's information management systems and managed internally by administrators. This survey tool and administration back-end provides a dynamic environment to collect real time data, analysis and report generation via the dashboard for evidence-based decision making by mine management, and all datasets accessible via the survey tool deployed in a specific location can be accessed for further analysis.

All reports from this survey tool for the mine's main operations may be managed from a central point with the super administrator and subsequent surveys may be created for different operations and locations, at timely intervals. Built into the application are standardised dashboards that may be generated for decision-making purposes and towards subsequent appropriate interventions.

The survey tool uses a web-based application and is accompanied by a user guideline and video to ensure that both users and administrators on mines can implement and use the tool effectively. The open-source survey tool and accompanying support material are available on the Mandela Mining Precinct website.

CONCLUSIONS

During the commissioning of this project, it was determined that the Community and SMME Training-Needs Assessment Survey Tool allows for gaining an understanding of both current and future skills needs of communities and SMMEs. During the pilot phase, on-going stakeholder engagement and inclusion of communities was critical as they form a part of the wider mining ecosystem. The identification of skills needs within local communities may ensure that there is greater alignment between the expectations of mining operations and the skill development needs of communities.

Through the application of the tool, there is the possibility for mining operations to support the inclusive skills development of community members and SMMEs, so they are able to fit within the operational supply pipelines. Identified skills development for current and future mining, including entrepreneurship skills and business acumen may allow for mining sustainability. Furthermore the identification and inclusion of new technical skills sets applicable to other industries and further training and capacity building with community members and SMMEs will enable their preparation for future-oriented industries to support new and alternate economies.

ACKNOWLEDGEMENTS

We would like to thank the Mandela Mining Precinct for funding this project, through the MCSA and Department of Science and Innovation. The Mandela Mining Precinct is a public-private partnership between the Department of Science and Innovation and the MCSA and is a hosted programme of the CSIR. We would like to acknowledge Dr Sherin Ramparsad, SATCAP Programme Manager, for her guidance. We also thank the collaboration partners: RIIS for leading the project, Enterprises University of Pretoria for academic leadership, WinWin Consulting International for the development of the tool and SML for Change and The Impact Catalyst for their contributions to development and validation through the pilot testing and validation. Finally, we are grateful to the partner gold and PGM mines, stakeholders and individuals who participated in this project at all levels.

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Communications and engagement tool for local suppliers and small, medium and micro enterprises

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With mining modernisation, the awareness of communities' social and economic needs is important for a sustainable socio-economic environment. Meaningful engagement and communication with communities is critical. This project entailed the development of a communications and engagement tool for local suppliers and small, medium and micro enterprises to support localisation at mine communities and improve local procurement for local economic development. The tool development was informed by a literature review, data gathering, pilot studies and validation sessions. The tool is a web-based digital application that includes five features: checklists, frequently asked questions, notice board, resource library and query submission. The tool, a user-guideline and video were developed for potential use by South African gold and platinum group metal mines. The tool is not meant to replace current systems or processes at mines but rather to complement them. The tool is customisable, may enable decision-making, and is aimed at improving local procurement processes.

Keywords: Communication, engagement, SMME, procurement

INTRODUCTION

As the mining industry modernises, the awareness of communities' social and economic needs is important to ensure a sustainable socio-economic environment, even post-mining. As communities form a part of the mining ecosystem, their inclusion is critical, and how to engage and communicate with them more meaningfully is important. Equipping small, medium and micro enterprises (SMMEs) and surrounding communities with relevant training, and having effective communication and engagement tools may enable economic growth and transformation, innovation, entrepreneurship, and job creation to ensure current and post-mining communities survive and thrive.

A key issue for inclusion of SMMEs into local procurement systems is addressing their knowledge gaps regarding business processes, eligibility requirements and compliance with procurement and supply chain requirements by mines. The aim of the study was therefore to improve information flows and communication between local SMMEs and mining companies by creating a stakeholders' (SMME/local suppliers) Communications and Engagement Tool.

A local supplier or SMME communications and engagement tool was developed for potential use by South African gold and Platinum Group Metal (PGM) mines. The purpose of the tool is to support localisation at mine communities and to improve local procurement for local economic development.

This study was commissioned by the South African Mining Extraction, Research, Development and Innovation (SAMERDI) Successful Application of Technology Centred Around People (SATCAP) Programme of the Mandela Mining Precinct. The SATCAP programme aims to understand the effects, impacts and challenges of mining modernisation on people in the mining and minerals sector. The focus of this work package was on the environmental, social and governance (ESG) agenda, specifically on the 'social' or 'people in mining' aspect to support mining modernisation. The study was undertaken by The Research Institute for Innovation and Sustainability (RIIS) in collaboration with their research partners, Council for Scientific and Industrial Research (CSIR), Mining Dialogues 360° and WinWin Consulting International. The mine partners included a multi-commodity mining company, a gold and a PGM mining company.

This paper is based on a study conducted by Naidoo, *et al*., (2023) detailed in an unpublished report titled, *SATCAP 2022 Final Report – Stakeholders (SMME/Local Suppliers) Communications and Engagement Tool*.

OBJECTIVES

The objectives of the study were three-fold:

(i) To consider and learn from the various approaches and practices from industry (locally and globally) that are related to communications and engagement with local suppliers/SMMEs;
(ii) To develop a stakeholder (local suppliers/SMMEs) communications and engagement tool, and avail for potential use by gold and PGM mines (Social Performance, Procurement and Enterprise Development teams); and
(iii) To pilot a tool to support SMMEs/local suppliers' engagement, towards greater localisation and procurement transformation and local economic development.

The tool is expected to provide a platform for mining companies and local suppliers/SMMEs on which to engage, provide information on potential opportunities and to support decision-making related to local economic development and transformation. The ultimate goal is to enable SMMEs to self-manage their compliance and ensure that they meet requirements for entry into the local procurement supply chain.

LITERATURE REVIEW

National and international best practice tools were reviewed as well as engagements tools used by mining companies. Benchmarking was done on SMME engagement and procurement portals to determine the gaps in engagement and communication and to define the features to include in the tool.

General Engagement Practices

Effective stakeholder management begins with a detailed stakeholder engagement plan. The plan should identify key stakeholders and include proposed methods or mediums of stakeholder engagement. It should also list the desired outcomes of the engagements. Stakeholders should be grouped according to their level of influence and interest, and based on said groupings; communication needs for specific stakeholder groups should be established. Best practice involves tailoring information dissemination in such a way that it addresses the issues that specific stakeholders are most concerned about and provides this information in a format most accessible to them. Clear communication is an important part of good stakeholder management. Relevant information should be communicated in an objective, timely and transparent manner. Stakeholders should be encouraged to participate in two-way communications with the organisation and share their perspectives on an ongoing basis. Lastly, interactions with stakeholders should be recorded and tracked. To this end, employing stakeholder engagement software or an engagement tool of some kind can be hugely beneficial (Hendricks, 2019).

Engagement Practices by Mining Companies
Some mining companies group their stakeholders based on the level of influence they have on the business, the effectiveness of existing engagements with them, and the level of alignment required in their relationship to realise their objectives. An executive or champion is assigned to manage the relationship with the stakeholder group and communicate issues to the board members (Implats, 2021). Other mines leverage off supplier events, local and host community procurement forums, supplier capability development initiatives, digital platforms and a responsible sourcing programme (Anglo American, 2022).

The literature review revealed that several mining companies have ongoing Enterprise Supplier Development (ESD) initiatives that support SMMEs through mentorship, business training and coaching, and assistance with preparing bid proposals (Muir, n.d.). This finding suggested that the engagement tool can be used to support these functions further and assist in simplifying the communication flow and engagement between SMMEs and mining companies.

Engagement Practices by Non-Mining Companies
The manufacturing industry was identified as similar to the mining industry in terms of stakeholder relation practices, thus warranting a review of their communication channels. Communication channels that were used to engage with suppliers ranged from paper, email, faxes, and telephone (the most common) to internally hosted portals, electronic data exchange and collaborative hubs (The Manufacturer, 2018).

Challenges faced by SMMEs
Key challenges faced by SMMEs included accessing opportunities at the mines and SMME/local supplier readiness for the procurement process. Another key challenge includes the need for clearer communication of procurement opportunities, as well as easy access to information surrounding procurement plans and specifications. SMMEs were also found to require training and guidance around procurement processes, financial literacy, and completion of supporting documentation for tender proposals (Antonites & Truter, 2010; Kalidas, *et al.*, 2020).

It has been suggested that the ability to streamline procurement opportunities, funding solutions and supplier development to a single location could remove these barriers to entry for SMMEs and lead to fairer, clearer, and more transparent stakeholder interactions (Mkhungo, 2022).

Further desktop research and introductory engagements also highlighted the challenges faced by suppliers pertaining to the procurement process. These challenges include:

(i) Limited understanding of procurement requirements and thus being unable to participate in procurement opportunities;
(ii) Inaccessibility to funding due to requisite documents not being in place, resulting in the SMME/local supplier not being able to provide services to the mine (Outsourced Finance, 2019);
(iii) Human resource limitations due to inability in finding qualified personnel to employ (Outsourced Finance, 2019; van Vuuren, 2022);
(iv) Inadequate time provisions for the resolution of general procurement issues; and
(v) Poor access to business networks that could aid business growth (Outsourced Finance, 2019).

Six procurement and SMME portals were reviewed to determine the gaps in communication and engagement relating to procurement information. Five of these portals were from mining companies and one of the portals belonged to a retail business. The gaps are presented in the Results and Discussion section.

METHODOLOGY

The project inception phase included alignment meetings with research partners, and briefing sessions with Minerals Council South Africa (MCSA) and the mining partner companies. Briefing notes and permission letters to potential project participants, requesting their consent to participate in the project were also developed and distributed.

A literature review was undertaken to gain an understanding of best practice tools used both nationally and internationally. Engagement tools used by mining companies were also reviewed. Benchmarking was done on SMME engagement and procurement portals to determine the gaps in engagement and communication and to define the features to include in the tool.

Ethical clearance was obtained from the CSIR Research Ethics Committee (reference number: 406/2022) to engage with and collate data from study participants.

Qualitative data was collected through two focus group discussions and multiple co-creation workshops with more than five stakeholder groups. The stakeholders included representatives from mining companies, community-based organisations, non-governmental organisations, and local suppliers/SMMEs. The mining companies included the following departments: mining and engineering, social performance, ESG, stakeholder relations, training, women's forum, human resources, and supply chain/procurement departments.

The tool and application design were based on the literature review and stakeholder inputs. The tool was developed with collaboration partners. A feedback template was used to facilitate reviews and refinements to the tool. The tool design was based on adding features and checklists that were deemed to be important in providing SMMEs and suppliers with a self-managed digital solution. The application was developed on a web-based platform accessible by a smart phone, tablet or a laptop.

Three physical and two virtual pilot studies were undertaken with existing and potential SMMEs during October 2022. Approximately 120 national participants were requested to interact with the tool and provide feedback on the various features. The online usability survey was administered by the facilitator for both the physical and virtual pilots, and in total 39 people completed the online survey, 88% of these attended a physical session and the remaining 12% completed the online survey after participating virtually. The usability survey was also administered physically by the facilitator asking the questions to the audience and noting down feedback qualitatively; this qualitative feedback is separate from that which was completed by the 39 online surveys. Virtual pilots enabled participants belonging to communities of small to medium sized mining companies to participate to ensure the tool caters for the wider mining industry. The tool was reviewed and refined based on the outcomes of the pilot studies. A user-guideline and video were developed for the transfer of the tool to the mining partners and to the wider industry.

RESULTS AND DISCUSSION

Tool Design Considerations and Tool Development

The findings from the literature review, gap analysis and stakeholder engagements facilitated the design of the tool.

Literature Review and Gap Analysis

The following gaps and insights were noted from the review of the six procurement and SMME portals:

(i) Different levels of development of procurement portals resulting in varying interfaces and content may confuse SMMEs/local suppliers;
(ii) Business development support for SMMEs is not easily accessible within these portals which may result in higher than necessary levels of self-disqualification;
(iii) The lack of a comprehensive list of documents/details required upfront when registering to become a supplier or submitting an expression of interest, may result in the user needing to spend additional time acquiring those details during which period the procurement

opportunity may close;

(iv) The lack of consistency in general details required by different mining companies from suppliers may result in needing to apply to multiple mining companies for opportunities which may be more challenging; and

(v) Basic explanations of procurement concepts were lacking.

Additionally, based on the literature review it was found that the tool should meet the following five criteria:

(i) Offer targeted experiences – the tool should be able to gather information on the events needed by SMMEs and local suppliers, e.g., training webinars, networking events, tailored engagements that speak to specific procurement opportunities;

(ii) Enable in-person meetings - the tool should be used to communicate town hall sessions where the SMMEs and local suppliers can engage with the mining companies;

(iii) Elicit feedback - the tool should be used to send periodic updates with questions and answers between mining companies and SMMEs/local suppliers on procurement opportunities;

(iv) Encourage transparency - the tool can be used to update SMMEs/local suppliers on issues critical to them to encourage transparency, e.g., through newsletters posted on the tool; and

(v) Meet expectations - the tool can be used to hold mining companies as well as SMMEs/local suppliers accountable for their actions by holding frequent polls to track improvements in localisation of procurement.

The challenges faced by the SMMEs/local suppliers (as highlighted in the Literature Review section) were taken into consideration for the design of the tool survey questions, the tool design, checklists and functionality elements.

Stakeholder Engagements

The findings from the literature review and gap analysis were validated through two focus group discussions. The first focus group included eight stakeholders represented by potential suppliers, enterprise development (ED) practitioners and business forums.

The second focus group discussion was held with 25 representatives from various departments in a PGM mining company. The purpose of this engagement was to obtain validation on the need for the tool. The key insights obtained from these engagements are noted in Table I.

Table I. Key insights from stakeholder engagements

Stakeholder group	Key insights
Potential suppliers, ED practitioners, business forum representatives	(i) The local supplier base capabilities in a given location may vary, thereby suggesting that the needs amongst SMMEs/local suppliers may differ. (ii) There are challenges in understanding procurement requirements and thus putting together the requisite documents in the pre-application phase also differ. (iii) Challenges exist in information dissemination amongst suppliers hence an interactive information hub or application may address this. (iv) There is variability in the way different mining companies manage communication with SMMEs/local suppliers. The communication channels preferred are likely to be dependent on the position of the supplier in relation to the mining company. Existing communication channels include website notifications and in-person engagements. (v) Mines often do not have the systems and tools in place to monitor progress and the impact of localised procurement.

PGM mining company	(i) A tool that would enhance the quality of communication between SMMEs/local suppliers and supplement existing communication channels would be well received. (ii) In addition to supporting existing communication channels, the tool should also support ED and ESD initiatives in their communication and engagement with SMMEs/local suppliers. This can be done by using the tool to alert them of ED and ESD initiatives. (iii) Buy-in should be sought from smaller-scale mines to ensure that their needs are also addressed. (iv) SMMEs/local suppliers want access to procurement opportunities but lack certain technical abilities which prevent them from actively participating in these opportunities.

(*Source: Naidoo* et. al,. *2023)*

Tool Features

The SMME engagement tool is a web-based digital application that can be used via a smart phone, laptop or tablet. Based on a benchmarking exercise of various engagement tools, six features were initially selected from a list of 17, for incorporation into the project tool. These six features were checklists, frequently asked questions (FAQs), a resource library, a notice board, a discussion board, and a SMME/local supplier chat.

The conceptual tool included a chat feature, but this was later removed due to potential reputational risks, based on feedback from the SMMEs during the pilot studies. Reviews and refinements made to the tool will be discussed in the following subsections. The final tool incorporated five features, namely, checklists, frequently asked questions (FAQs), a resource library, a notice board, and a query submission feature.

Three checklists, namely the pre-application, post-application, and post-response checklists were developed to assist SMMEs with their procurement process. The questions in the checklists are presented as either multiple-choice, drop-down selections, open text fields or ratings scales. The checklists were accompanied by a series of FAQs. The purpose of the resource library is to provide a repository of useful business development information to SMMEs. The notice board can be used to disseminate information by the mining company to SMMEs, while the query submission feature can be used to relay procurement-related queries to the mining company as well as provide a two-way communication channel. Screenshots of the home page showing some of the features of the tool are depicted in Figure 1.

The tool also comprises a data analytics component and can generate reports presented as visual dashboards. The analytics are aimed at assisting mines with decision-making related to SMMEs. The analytics displays responses to selected questions from the checklists and can provide valuable information to inform ESD initiatives targeted at local suppliers. The analytics may enable mines to assess levels of SMME awareness regarding tracking of their applications and based on this assessment, changes could be proposed to the current vendor management systems. The visuals also provide an indication of SMMEs' perceptions regarding the ease of use of procurement portals, therefore enabling adjustment and/or targeted support to SMMEs. Examples of the analytics dashboards include a pre-application checklist analytics (Figure 2) and a post-application checklist for preferred medium of communication and service offerings (Figure 3). A summary report on SMME engagement readiness can also be generated based on all responses received, as depicted in Table II.

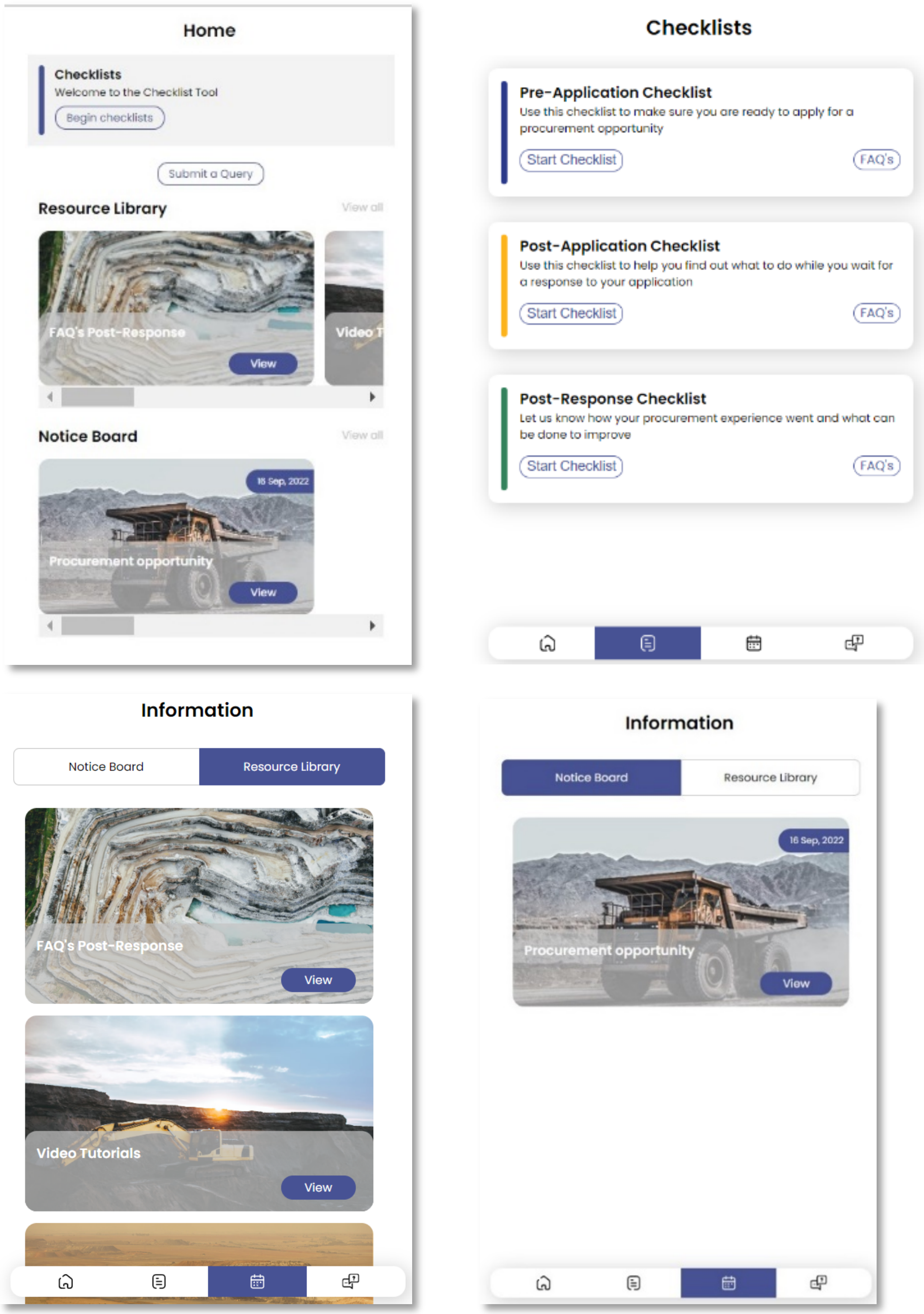

Figure 1. Home screen of tool showing checklist, notice board and resource library.

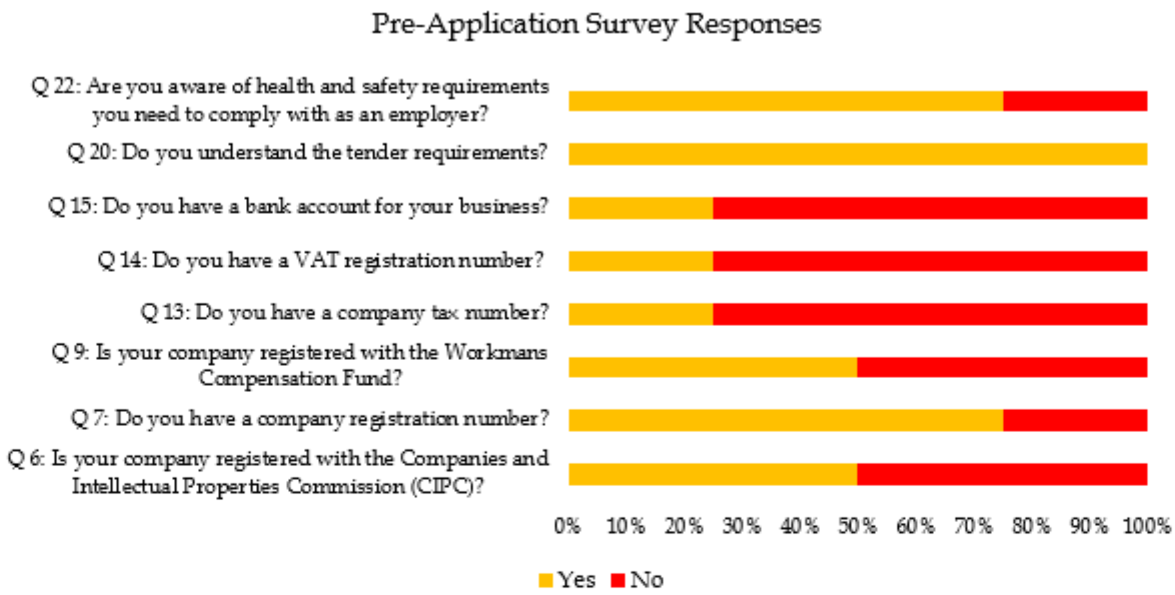

Figure 2. Pre-application checklist analytics.

Figure 3. Post-response checklist regarding communication medium and service offerings.

Table II. Summary report of SMME readiness for engagement with the mine

Checklist	Items	Status: Green – 75% or more responders answered yes Yellow – 50% or more responders answered yes Red – Less than 50% of responders answered yes
Pre-application	Registration with the CIPC	
	Company registration number	
	Workman's compensation	
	Health and safety	
	Company tax number	
	VAT number	
	Bank account	

	Understanding of tender requirements	
Post-application	Monitoring of application status	
	Knowledge of where to check application status	
	Knowledge of pre-application checklists	
Post-response	Ease of uploading documents	
	Ease of understanding vendor portal	
	Knowledge of navigating a vendor portal	

Pilot Studies
The following key insights were acquired from the pilot studies:

(i) The tool was positively received and the feedback from stakeholders was related to the content and wording and not major development changes;
(ii) Experienced suppliers may not gain as much value from the tool as would newer suppliers;
(iii) A clear distinction needs to be made between the purpose of the tool and the purpose of the current vendor management systems/vendor portals; and
(iv) When developing such a tool, socio-economic context is important to ensure that the tool can be adopted by the intended users.

The tool was reviewed and refined based on the feedback from stakeholders and the outcomes of the pilot studies.

Refinement and Finalisation of Tool
The amendments included rephrasing of the checklist questions, addition of new response options to the questions, addition of new questions, removal of irrelevant questions, amendments to the reporting dashboards, fixing of bugs and ensuring consistency throughout the tool.

The key amendments to the tool included the following:

(i) The SMME/local supplier chat feature was removed after consultation with SMMEs as there were concerns that this feature could lead to reputational damage for both the SMME and the mine;
(ii) The discussion board was removed and replaced with a 'query submission' feature to avoid misuse and to ensure efficient responses to SMMEs;
(iii) The position of the FAQs was changed; and
(iv) Minor content changes were made, and new questions were added to the checklists.

Transfer to Industry
The tool was transferred to the participant mining companies through a user-guideline and video which was showcased at the SATCAP Transfer to Industry Workshop on the 2 March 2023. The hybrid workshop was hosted at the Mandela Mining Precinct in Johannesburg and via Microsoft Teams. The guideline provides instructions on how to navigate the tool for the respective user groups including the SMMEs/local suppliers, administrators, managers, and Information Technology (IT) teams. The tool is being made available for potential use by industry through the Mandela Mining Precinct website.

Screenshots of the guideline and the video are shown in Figure 5 and Figure 6 respectively.

Figure 5. Screenshots of the tool user-guideline.

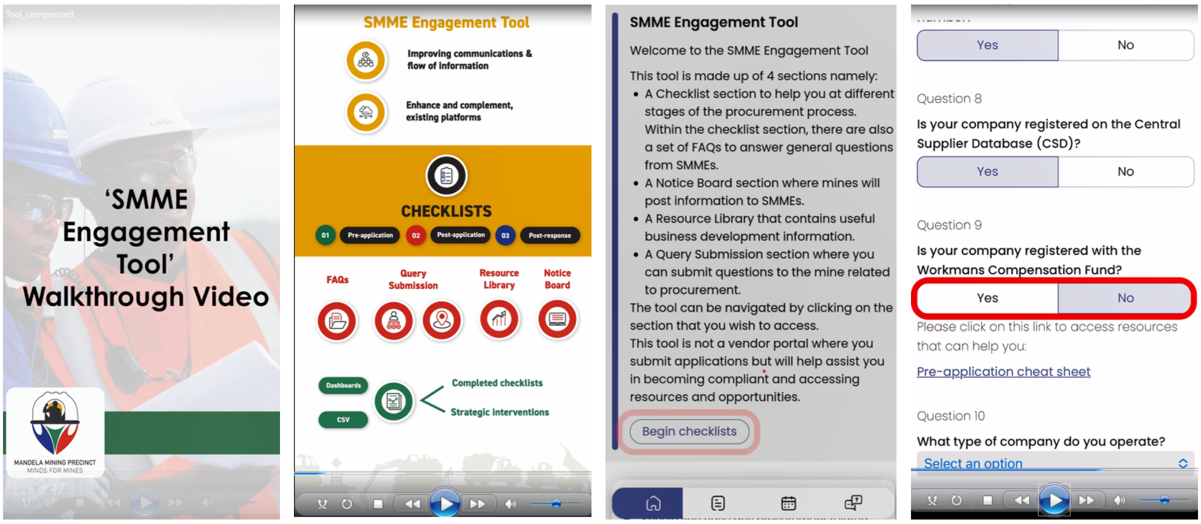

Figure 6. Screenshots of the tool walkthrough video.

The tool is available to be incorporated into current mine IT systems with the provision of the open-source code, the aid of the guideline, and technical assistance from the development team. Within the mine, this tool could be used by the procurement team, ED and supply chain teams, stakeholder relations team, incubators or any team that engages with local SMMEs for the purpose of advancing local procurement. Stakeholder engagements are necessary for the mines to adopt the tool and embed it successfully into their systems and processes.

Benefits of the Tool

The tool has been specifically designed for local SMMEs with their needs in mind. There are several benefits to adopting the tool for both the mining company and the SMME/local suppliers. These include:

(i) Improvement to local procurement processes by providing local SMMEs with a competitive advantage through guided assistance;
(ii) Specific user needs can be addressed as the tool contains several distinct features that perform a specific function;
(iii) The digital tool is designed in open-source code and the content is fully customisable and can be incorporated into current mine information management systems;
(iv) The tool contains analytics and downloadable data files that can provide information to end-users for decision support;
(v) The tool may be fully hosted by the mine with no hosting or subscription cost; and

(i) The tool is a web-based application and is compatible with a variety of mobile devices, including smart phones, tablets and laptops.

CONCLUSION AND RECOMMENDATIONS

A local supplier or SMME communications and engagement tool was developed for potential use by South African gold and PGM mines. The purpose of the tool is to support localisation at mine communities and improve local procurement for local economic development. The tool does not have any hosting or subscription costs. It contains defined features that address specific needs. The tool is a web-based digital application and is available for use on a mobile device e.g., smart phone, tablet, or laptop. The tool is fully customisable to suit the needs of a specific mining operation. While mines do have vendor portals, the information that is provided by this tool pertains to SMME/local supplier business development and procurement support, as opposed to commercial business process support that is provided by the vendor portal.

This tool is not meant to replace the current systems or processes on mines, but rather to supplement them. Mining companies may use this tool in decision-making related to SMMEs by analysing the data generated by the tool. The ultimate goal is to enable SMMEs to self-manage their compliance and ensure that they meet requirements for entry into the local procurement supply chain. These have been issues that mines and SMMEs are grappling with, which this tool seeks to address.

For customisation of the tool a mining company may consider adding more or tailored questions to the checklists. Multiple languages may be incorporated, or translation options may be included into the tool. Integration of a mechanism for tracking SMME applications through the procurement process into existing on-mine systems could potentially improve the overall use of a tool for a specific mining operation.

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We would like to thank the Mandela Mining Precinct for funding this project, through the MCSA and Department of Science and Innovation. The Mandela Mining Precinct is a public-private partnership between the Department of Science and Innovation and the MCSA and is a hosted programme of the CSIR. We would like to acknowledge Dr Sherin Ramparsad, SATCAP Programme Manager, for her guidance. We also thank the collaboration partners: RIIS for leading the project, CSIR for academic leadership, WinWin Consulting International for the development of the tool and Mining Dialogues 360° for their contributions to development and validation through the pilot testing and validation. Finally, we are grateful to the partner gold and PGM mines, stakeholders and individuals who participated in this project at all levels.

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Paleesha has spent most of her career in the chemicals and energy sector and is experienced in decision support as a result of analyses performed in various environments such as business development, supply chain and sustainability. She has conducted multiple benchmarking studies in both the sustainability and marine fields and is adept at identifying opportunities for collaboration and reporting on international trends. Over the past two years she has been involved in the development of the innovation ecosystem for the Freeport Saldanha Innovation Campus. She has led the project on the conceptualisation, benchmarking and development of the digital application - SMME Communications and Engagement Tool.

Community social-needs assessment tool

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Mining, mining modernisation, and eventual mine closure have impacts on mine communities, and an understanding of community socio-economic needs is necessary. This understanding is further important for the conceptualisation of communities that are self-sustainable beyond the closure of mines. The aim of the project was to develop a community social-needs assessment tool for potential use by gold and platinum group metal mines. The project was informed by desktop research, literature review and stakeholder engagement, and the tool was developed for use and piloted with industry partners. The assessment tool that was developed comprises of questionnaires for small, medium, and micro enterprises, community members, community-based organisations and non-governmental organisations, a notice board, and a resource library of useful information. Implementation of the tool is expected to generate an improved understanding of community socio-economic needs towards shared value creation to support environmental, social and governance agendas.

Keywords: Alternate economies, co-creation, community engagement, localisation

INTRODUCTION

Shareholders demand a balance of profitability, planet, and people. For mines' licences to operate, Social and Labour Plan (SLP) targets need to be met, amongst other aspects, in terms of community social responsibility. The Sustainable Development Goals (SDGs) are a call for action towards ending poverty and other social deprivations, with aligned strategies to improve health and education, reduce inequality, and spur economic growth – with consideration of the environment. It is essential for mines to act in this regard. Mining impacts on mine communities, and an understanding of community socio-economic needs is necessary. These impacts include environmental, social, and economic outcomes within communities. The dependence of host communities on mines needs to be considered (Ritchken, 2018). The modernisation of mining is a further factor to consider, and this has been accelerated by the COVID-19 pandemic. In addition, the legacy that mines leave behind once resources are depleted and shafts close is crucial. Improved understanding of the impacts of mining and modernisation is important for the conceptualisation of communities that are self-sustainable beyond the closure of mines. As such, the need to develop a tool to assess community socio-economic needs was identified.

The aim of the project was to develop a community social-needs assessment tool for potential use by gold and platinum group metal (PGM) mines. The tool is intended to acquire data on the changing socio-economic concerns and needs of mining community members and organisations, and information about local initiatives and businesses, to assist mines to effectively support community development. These organisations include small, medium, and micro enterprises (SMMEs), non-governmental organisations (NGOs) and community-based organisations (CBOs). NGOs were considered key role players in determining the 'real' socio-economic needs of communities in this project. The tool enables the assessment of current and perceived future needs, which may help the strategic thinking of mines, and identify potential black industrialists, and asset bases within their local community.

The identification of mine-led and community-led initiatives would inform the decision-making processes of the mines to better empower communities to continue meeting their needs.

The objectives of the study were:

- To uncover various approaches and practices from industry (locally and globally) relating to community social-needs and related survey tools;
- To avail an assessment tool for potential use by gold and/or PGM mines; and
- To pilot the assessment application for securing of community social-needs to support social indicators.

The project was commissioned by the Successful Application of Technology Centred Around People (SATCAP) Programme of the Mandela Mining Precinct. SATCAP aims to understand the impacts of mining modernisation on people in the minerals sector. In 2022, the focus of SATCAP was to support the environmental, social and governance (ESG) agenda and, in particular, the social aspect. The project (Work Package 3.2) was aligned to three concurrent SATCAP projects (Work Packages 2.1, 2.2 and 3.1) that focused on tools for the assessment of training needs, digital leadership competencies, and SMME engagement, respectively.

A collaborative research team was commissioned to develop and pilot the community social needs assessment tool. The project was led by the Research Institute for Innovation and Sustainability (RIIS), in collaboration with the Council for Scientific and Industrial Research (CSIR), Mining Dialogues 360°, WinWin Consulting International, and key mining partners, including a gold and a multi-commodity mining company (Likaku *et al.*, 2023).

LITERATURE REVIEW

A review of literature was conducted to gain a better understanding of mining community needs, industry approaches, leading practices, and related existing tools.

The SLPs for the areas where the envisaged pilot testing was to be conducted, were reviewed. SLP initiatives at the multi-commodity mine company included farming initiatives, water supply, road construction, stormwater management, clinics, schools, multi-purpose centre and community health centre development, and sports field upgrading. Initiatives at the gold mine included a human resource development programme, and local economic development programmes such as building school laboratories and classrooms, a community care centre, park, ICT centre and health care clinic, upgrading or development of sports facilities, and support for social entrepreneurship initiatives and agricultural projects. It was evident that SLPs were not always easily accessible to communities. Additionally, individual mine SLPs are often duplicated and uncoordinated (Ritchken, 2018).

The concept of Asset-Based Community Development (ABCD) was identified as an approach for tool design in this project. ABCD focuses on the linkages between the micro-assets in the community and the macro-environment in the province or country (Mhar, 2022). It was evident that the identification of current asset bases or local initiatives in the community can be helpful for understanding the socio-economic needs in the community, and who can be supported to better contribute to the local economy. Existing asset bases in the specific mining communities involved in the tool piloting included:

- Social or human assets e.g., health facilities sports fields, schools, malls, and community centres;
- Economic assets e.g., road infrastructure, water and sanitation, electricity, agriculture, and tourism; and
- Environmental assets e.g., dams, rivers, parks, and conservation areas.

Further research was conducted to understand potential alternative economies for post-mining communities. Some of these findings are described in Table 1. The main streams of alternative economies that were identified included mine waste beneficiation and waste-mining, recycling and waste management, regenerative agriculture, agro-processing and re-forestry, carbon alternative and renewable energy production, tourism and cultural attractions, and information and communications technology (ICT). These alternative economies can be used for the creation of direct and indirect jobs and resources, especially post-mine closure (Aleke and Nhamo, 2016; Bizcommunity, 2016; Burger, 2022; Hartley *et al.*, 2019; Maia *et al.*, 2011; Nwaila *et al.*, 2021; Parliamentary Monitoring Group, 2021; Tshivhengwa, 2019).

Related tools and applications that were available both locally and internationally, and from mining and other sectors, were assessed for applicability for this project, and a gap analysis was conducted. Tools used include mobile applications and paper-based surveys. Examples of leading practices that were identified included the International Finance Corporation (IFC) Performance Standards on Environmental and Social Sustainability, the International Council on Mining and Metals (ICMM) Community Development Toolkit and Anglo-American Social Way principles and guidelines (Anglo-American Social Way, n.d.; ICMM, 2012; IFC, 2012). The IFC Performance Standards describe ideal community engagement practices, which refer to the ethical practices used by an organisation to minimise the implications of their operational activities on community health and well-being. The ICMM Toolkit consists of 20 practical tools and provides comprehensive guidance for key steps of the mining cycle. The Anglo-American Social Way Toolkit gives direction on how an organisation's Socio-Economic Development strategies can effectively help stakeholders achieve long-term gains in their well-being at the individual, home, and/or community level.

In addition, specific tools were assessed as benchmarks to inform the project tool design and layout. These tools included the Social Screening Tool of the American Academy of Family Physicians (AAFP), the Accountable Health Communities Health-Related Social Needs Screening Tool, and the SDG Impact Assessment Tool (UN-SDSN) (AAFP, 2019; Centres for Medicare and Medicaid Services, 2019; SDG Impact Assessment tool, n.d.). The Social Screening Tool identifies social determinants of health, such as food, transportation, housing, utilities, safety, employment, financial status, and childcare. The Accountable Health Screening Tool is used to assess patient needs where community programmes can potentially assist, such as housing, transportation, food security, utility needs, and safety. The UN-SDSN is a free online learning instrument that enables self-assessment of how a certain practice, institution, or development impacts SGDs and how to prioritise future activities.

Table I. Alternative economies

Alternative economies	Social needs
Mine waste beneficiation and 'waste mining'	• Establishing diverse sources of employment • Health/medical services • Water treatment • Uncontaminated land/housing • Education and awareness/educational and training facilities • Mine-waste facilities
Recycling	• Recycling resources, e.g., equipment needed for recycling (metal mining and exploration) • Safety/appropriate clothing (masks, gloves, overalls, boots, etc.) • Ablution facilities (provisions for temporary toilets, clean drinking water, etc.) • Recycling centres (buy-back centres and drop-off centres) • Recycling awareness and educational programmes • Logistics and infrastructure • Scrap treatment • Health facilities
Regenerative agriculture, agro-processing and re-	• Agricultural advisory services • Rural finance

forestry	• Agricultural technology • Small-scale irrigation facilities • Rural enterprise development • Animal health services
Carbon alternative and renewable energy production	• Employment • Educational awareness • Health facilities and services • Energy access
Small/light manufacturing, industrial parks – based on District Development Model	• Development if integrated transportation infrastructure (on-site and off-site) • Communications infrastructure • Integrated utilities infrastructure • Solid waste collections, transport, and treatment facilities • Water source development • Wastewater treatment and recycling • Development of knowledge, training and research support infrastructure • Air quality monitoring system • Healthcare services and facilities/emergency services • Logistics and parking centres • Environmental permits/compliance requirements and licences
Tourism and cultural attractions	• Tourism awareness training • Tourism skills training • Leadership and mentorship • Tourism facilities • Vehicles and licences (transportation) • Compliance requirements • Education and cultural awareness • Financial resources • Accommodation • Employment
Information and Communication Technologies (ICT)	• Internet access/connectivity • Technological infrastructure (phones, computers, connectivity facilities, etc.) • ICT awareness (especially in rural communities) • Language of resources • Online access centres • Community centres

(Sources: Aleke and Nhamo, 2016; Bizcommunity, 2016; Burger, 2022; Hartley et al., *2019; Likaku* et al., *2023; Maia* et al., *2011; Nwaila* et al., *2021; Statista, 2021; Tshivhengwa, 2019)*

METHODS

Research Design

An explanatory design was incorporated into the study to provide a functional explanation for why the solution has specific components as per the design requirements. A design thinking approach was followed, which included the steps of understanding and synthesising data; ideation and analysis; and testing, iteration, and refinement.

Study Setting and Population

The study context was the South African mining industry and surrounding communities. The study participants included Community Engagement and Social Performance departments at mines, community leaders, NGOs, CBOs, and subject-matter experts.

Data Collection Tools and Procedures

Data were collected during literature review and stakeholder engagements to inform the tool design. Focus group discussions and co-creation workshops were held with mining partners and external stakeholders for tool characterisation. The survey tool content was drafted, and validated in sessions with internal team members, mine representatives (including Social Performance, Stakeholder

Relations, and Supply Chain Development teams), and subject-matter experts. A pilot version of the survey tool was developed using an iterative process. A physical pilot was conducted with 38 participants, including community engagement practitioners, community leaders, and SMMEs. Thematic analysis was conducted on participants' responses. The tool was refined based on insights received. The transfer of the tool has been facilitated by the development of a guideline and video tutorial.

Ethics Approval

Ethics approval to conduct the study was granted by the CSIR Research Ethics Committee (Ref: 405/2022).

RESULTS AND DISCUSSION

Stakeholder Engagement

Engagements, including focus group discussions, co-creation sessions, and smaller working group sessions, were held to gain insight into mine communities' socio-economic needs and tool design considerations. These engagements were held with participants from mining companies, including Social Performance and Supply Chain Development departments, CBOs and NGOs, and project partners. Findings from the engagements are indicated in Table II. From the discussions it was evident that understanding the direct needs of the communities was important for making the right decisions relating to imminent mine closure. Additionally, it was evident that there were communication barriers between community members and the mines. Regarding tool design characteristics, mine partners indicated that engagement with communities and stakeholders occurred via community forums and informal and formal interviews. The use of a zero-rated data, learning platform was also mentioned, that allows for engagement between communities and mining companies.

Assessment Tool Application Development

The content for the assessment tool was drafted and iterated onto a digital application. The tool was designed as an application with a survey component, resource library, and noticeboard that would feed into a platform with dashboards that would present the various community and SMME needs currently and for future alternative economies. The survey comprised of questionnaires for community members, SMMEs, CBOs, and NGOs. The survey questions were segmented into specific categories to get information about demographics, education and skills, employment, available facilities and infrastructure, current needs, and SMME services and support. Table III indicates the categories of questions included in the survey. The tool was designed using open-source code and as a stand-alone web-based application that is accessible on a smartphone, laptop, or tablet.

Table II. Stakeholder engagement insights

Stakeholder group	Insights
Mining partners	• The mines are looking to understand the direct needs of the community to make better decisions about how to assist the community with their needs. • Due to the various grievance mechanisms that they have already, this tool should not be another grievance-airing instrument for the community to the mine's management. • There is room for tools to supplement those already in place. For some mines the use of formal and informal methods of community engagement, and surveys and questionnaires were prevalent. Other mines had begun the piloting of apps to gain data for their internal platforms. • Some mines already have operations in the sectors that are earmarked as alternative economies. • Mines can also benefit from identifying standout businesses and black industrialists in their community to direct their assistance accordingly in some of the identified alternative economies. • The tool should be able to identify already existing initiatives and assets that are empowering the economy and either support them or partner with them. • Community and SMME's socio-economic needs are evolving; the tool should be able to capture the growing needs.
CBOs and NGOs	• The priority needs to be on empowering the community to do their own engagement with the mine and to remove the middleman. • Community-based organisations are the best way to identify the key points of the marginalised groups and existing assets to get information to the mines. • The community often engages with the mines, but the latter are not transparent and do not avail information at the same level as that shared with regulators. Mines need to improve their way of giving communities information that they may need to be aware of, regarding their operations. • With the tool design, capacitating the local community is a major priority to ensure that they know how to use it. Similarly, mine personnel need retraining to be sensitive to and capable of using the participatory methodologies that are central to ABCD approaches. • There are challenges with having a tool that requires the use of a cell phone and other devices as communities require some level of digital literacy and access to internet/data.
Project partners	• ABCD methods are the best way to ensure that the communities can thrive post-mining as these identify and empower existing local businesses and initiatives. • There are other initiatives already in place that are not mine-led in the communities around the mine. • Agriculture is a standout post-mining economy. • Mining companies face local procurement constraints, as SMMEs are not adequately ready to tender for work with the mines. • There are issues in finding a meaningful way to engage with SMMEs to present opportunities that are available now versus those that will be available in the future. • Soft skills are an integral part of the modernisation of mines. • The language of the tool should be clear and concise to assist the understanding of various participants. • The tool will be web-based and not a catch-all application. • Accessibility is a key aspect to be taken into consideration. • Language limitation regarding open text inputs.

(Source: Likaku et al.*, 2023)*

Table III. Survey question categories

Category	Respondent group	Social needs
Current needs	Community	• Education • Environmental needs • Livelihood needs • Skills improvement • Access to jobs • Finances to start a business • Transportation • Security • Water • Food • Shelter/housing • Healthcare • Recreational centres
	SMMEs	• Finance/funding • Skills • Collaborations and partnerships • Learning and development • Infrastructure • Connectivity • Utilities • Security
Future needs	Community	• Skills needs • Clean air • Healthy fertile soil • Access to land • Pollution-free environment • Functioning waste management system
	SMMEs	• Collaboration and partnerships
Current asset bases	Community	• Health facilities • Community hall • Primary and secondary (high) schools • Police station • Tuckshops/spaza shops • Retail shopping centre • Transport stations • Sports and recreational facilities • Solid waste disposal and recycling depot • Post office • Community agriculture/training/gardening areas
	SMMEs	• Natural assets
Future asset bases	SMMEs	• Health facilities • Community hall • Primary and secondary schools • Police station • Tuckshops/spaza shops • Transport stations • Sports and recreational facilities • Solid waste disposal and recycling depot • Post office • Agriculture/farming/gardening

(Source: Likaku et al.*, 2023)*

Pilot Testing and Validation

Various levels of validation took place to advance the tool from draft content questions into a usable application. The assessment tool was reviewed, tested, and validated by project collaborators and mine partners before and after the pilot testing. Feedback regarding language, syntax, and usability of the tool was provided and then incorporated into the tool. This collaborative process helped to ensure that the surveys were appropriate for the target users. Onsite pilot testing for the tool was conducted in September and October 2022. The study participants included community engagement practitioners, community leaders, and SMMEs. The physical pilot testing sessions were scheduled to be three hours long, and included the following three phases:

- Orientation phase – project introduction, question and answer session, and request for informed consent;
- Tool run-through – facilitated progression through the tool content on laptops, smartphones, or computers; and
- Tool validation with participants – focus group discussions to gain verbal feedback about the tool.

Feedback was received regarding the usability, functionality, language, and structure of the tool. During the pilot, it was also determined that ongoing stakeholder engagement and inclusion are critical for the success of the tool. Pilot testing feedback was collated and incorporated into the following application iteration, as per the section below.

Final Tool Development

The final application comprises a survey tool, notice board, and resource library. The survey tool consists of 37 questions for community members, CBOs and NGOs, and 44 questions for SMMEs. The question formats include multiple choice, checkboxes, drop-downs, and open texts. Each participant needs to provide consent before they proceed to the survey. The notice board allows space for mines to disseminate information directly to community members and SMMEs. The resource library acts as a repository of useful information about socio-economic needs and alternative economies. Figures 1 & 2 show the layout of the application pages.

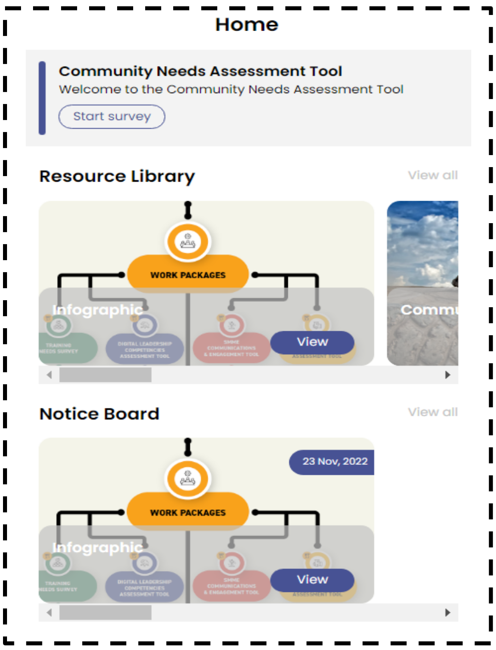

Figure 1. Home screen of application.

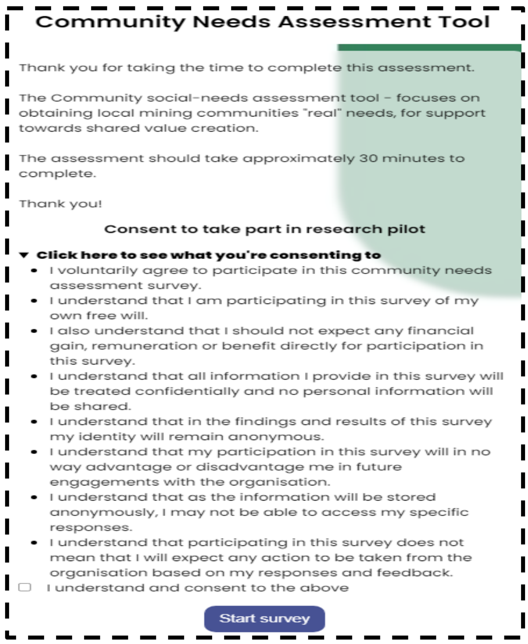

Figure 2. Survey page and consent information.

The application is housed on a web-based platform and is expected to be managed by mine administrators. Mine administrators will be able to create localised surveys for different operations and are expected to host and manage the generated database. Built into the application are standardised dashboards that can be generated for decision-making purposes towards appropriate interventions, as determined by mines.

Reporting outputs that the tool can create include the following:

- Current community challenges report
- Future community needs report
- Current SMME needs report
- Future SMME needs report
- Community asset bases report; and
- Future SMME beneficiation of assets report.

Traffic light/aggregator reports are also generated for mining partners to assist with data analysis by outlining areas of socio-economic needs that require support.

Recommendations for future enhancement of the application include customising the tool to include other languages used in mining communities, adapting the tool to capture evolving needs, and disseminating the tool in collaboration with SATCAP WP 2.1 (community/SMME training needs survey tool) to ensure that all needs are considered.

Transfer to Industry

The tool, along with a guideline and video to support the use of the application, are availed on the Mandela Mining Precinct website. Mines will be able to download the open-source coded tool, and there is no hosting or subscription cost. Internal and external mechanisms are recommended for the transfer of the tool within mining operations and across the South African mining industry, respectively. Internal mechanisms include integrating the application into community development initiatives at the mines, identifying a champion to drive the use of the tool, and issuing communication about the tool throughout the company. External mechanisms to increase awareness of the tool, include promoting the tool through online platforms and communication channels, conferences or symposiums, and academic papers.

CONCLUSION AND RECOMMENDATIONS

Implementation of the tool is expected to generate an improved understanding of community needs towards shared value creation to support the ESG agenda. However, the implementation of community-based initiatives would need to be dealt with in collaboration with NGOs, CBOs, and mines in the surrounding community. In particular, the intended impact of the application includes:

- A better understanding of the asset bases in communities which can be supported by mines for further development;
- A better understanding of asset bases in communities that the mine can partner with to continue assisting in meeting the needs of the community;
- An understanding of SMMEs, high-performing entrepreneurs and black industrialists that can promote local economic development;
- Increased visibility and understanding of opportunities for economic growth post-mine closure for community/SMME members; and
- A continuous dataset of real-time community and SMME challenges that can direct mine decision-making on how to tailor their support.

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With over five years' experience in projects in various sectors namely, space, mining, innovation and, public B Pol Sci, B Pol Sci (Hons) (Development studies), M in African-European Cultural Relations health, Yankho's expertise focuses on analytically assessing and navigating intersections between politics, business, and society to ensure that human-centred solutions are proposed. While at RIIS, Yankho has supported the research and development of innovation ecosystems across Africa in the space and innovation industries. He has also led the development of the NGO social needs assessment and training needs assessment survey tools for the South African gold and platinum group metals mining sector.

Digital leadership competency assessment tool for SA mining operations

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The impact of digital changes in the mining sector has brought about the need to define and understand digital leadership competence. The aim of the study was twofold, the first being the validation of a commonly accepted definition of digital leadership competence; the second being the development of an open-source, online tool to assess the level of digital leadership competence within mining operations. Through pilot testing and stakeholder validation, the most representative digital leadership competency definition for the South African Gold and Platinum Group Metals mining sector was accepted as *the strategic use of a company's digital assets to achieve business goals.* A collaborative research team was commissioned to develop and pilot a Digital Leadership Competency Assessment tool ("the digital tool") for potential use by mining companies. The methodology included an iterative and design-thinking approach, with findings incorporated into the definition and digital tool design. The digital tool was piloted with appropriate stakeholders, including a platinum mine partner, to ensure pertinence, practicality, and system functionality.

INTRODUCTION

The project was commissioned by the South African Mining Extraction Research, Development and Innovation (SAMERDI) Successful Application of Technologies Centred Around People (SATCAP) programme of the Mandela Mining Precinct, utilising funding from the Department of Science and Innovation. SATCAP aims to understand the effects, impact and challenges relating to people in the mining modernisation process from all stakeholder perspectives. In 2022, SATCAP focused on the Environmental, Social, and Governance (ESG) agenda, with specific focus on the *'social'* or *'people in mining'* aspect. The ESG agenda necessitates a balance between people, profitability and the environment. The drive to modernise mines has raised questions around the readiness and adaptability of the workforce to this more digitised environment. In many instances, there is a limited understanding of the full digital competence levels of the mining workforce, including at the operator, supervisory, and managerial levels. The increase in understanding of digital competencies throughout the organisational hierarchy can support the implementation of Fourth Industrial Revolution technologies, just transitions (i.e. green or low carbon technologies, mechanisation, or automation), and increase healthy and safe production. Furthermore, there exists limited definitions in the mining industry of the underlying concept of 'digital leadership competence', making singular assessment and intervention tools challenging to develop.

In the context of modernisation, leaders at all levels will need digital leadership competence to drive digital transformation. A digital leadership competencies gap assessment tool is critical to support mining modernisation and enable effective digital transformation. Application of a leadership competencies gap assessment will allow for mines to identify gaps in the competencies and address these gaps through targeted development interventions. The research for this specific SATCAP work package was aimed at standardising a commonly accepted definition of digital leadership competencies for the South African mining sector. Following the development of an accepted definition, it was necessary for a Digital Leadership Competencies Gap Assessment tool ('the digital tool') to be developed for use by South African Gold and Platinum Group Metal mines. Within the study there was specific focus placed on operators, supervisors, and managers to support the implementation of Fourth Industrial Revolution technologies and just transitions. The following objectives were developed to address the two focus areas within the study.

- To define a commonly accepted definition of digital leadership competencies for the mining sector.
- To develop an open-source, online, project-specific tool for assessing the digital leadership competencies across operators, supervisors, and managers.

The aim of this conference paper is to outline the methodology incorporated in the study, discuss the findings, and illustrate the tool developed.

METHODOLOGY

Research Design

The research design was informed by the context and objectives of the study. Within these parameters, it was decided that an exploratory design process be adopted with a human-centred, design thinking approach informing the design of the digital tool. The use of an exploratory design provided the research team with an opportunity to understand digital leadership competence within the South African mining sector and define a baseline for this metric, while prompting research into innovative solutions for assessing the digital leadership competence of the mining workforce. The exploratory design also provided an opportunity to examine defined key concepts (i.e., digital skill, digital proficiency, digital competence) and explain how these concepts are used in practice, as well as why these concepts are applicable to mining operations. The design also guided the research team toward a review of both national and international best practice tools and ensured a phased approach to the development of a practical tool for use by the South African mining industry, primarily by ensuring sufficient exploration into concepts, constructs and models pertaining to digital leadership competence.

Approach

The approach to the study was predominantly qualitative in nature, with a quantitative aspect included in the practical application piloting of the digital tool. As a departure point, the research team undertook a desktop study to determine and comprehend the various concepts and constructs of digital leadership within the mining sector. These results were subsequently debated and scrutinised by a panel of subject matter experts before being included in a draft version of the digital tool. A comparative matrix was developed which rated the various types of assessments against specific considerations (see Table 1). The findings from the matrix served as the baseline for the development of a draft outline of the digital tool. The research team subsequently undertook various focus groups with key stakeholders to ensure co-creation of the final version of the digital tool. The focus groups included representatives from the following stakeholder clusters:

- Managers from project mine, including:
  - Mine overseers
  - Human resource development practitioners
  - Technical managers
- Supervisors from project mine

- Operators and mine workers from project mine; and
- Subject matter experts (i.e., psychometrists, research institutions, and collaboration partners).

During these focus groups, an iterative process was used to ensure continuous alignment between the project objectives and practical relevance of the digital tool. A pilot programme was undertaken which included project mine operators and mine supervisors to understand the usability, functionality, language and structure of the digital tool. The pilot included 51 participants, divided into 28 operators and 23 supervisors.

Data Analysis
A comparative matrix was used to understand and evaluate the functional considerations of assessment tools used within the mining sector. Table I illustrates the comparative matrix used in the study.

Table I. Comparative matrix of types of assessments

		TYPES OF ASSESSMENTS			
		Questionnaire-based surveys	**Evaluation-type tests**	**Qualitative interviews**	**Gamification**
CONSIDERATION	Convertible into paper-based version	x	x		
	Requires human intervention			x	
	Distributable across a wide audience	x	x		x
	Easily modifiable to account for diverse languages				x
	Supports the use of supplementary information (i.e., visual aids)	x	x	x	x
	Easily modifiable to evaluate different job roles	x	x	x	
	Online usage	x	x	x	x
SCORE:		***5***	***5***	***4***	***4***

(Source: Mahadeo et al.*, 2023)*

It was evident from the comparative matrix that questionnaire-based surveys and evaluation-type tests are most effective within the mining environment, after establishing foundational knowledge from assessments in the mining sector. There was specific focus on three analyses areas, namely, (1) understanding and synthesising data, (2) ideation and analysis, and (3) testing, iteration, and refinement. The analysis incorporated a continuous refinement and reiteration between the various phases of the research study. The three analyses considerations are outlined as follows:

1. *Understanding and synthesising data:* Data was collected through desktop research, literature reviews, focus groups and pilot testing. By combining both primary and secondary sources of qualitative and quantitative data, the research team was able to evaluate existing digital tools and assessment practices across varying industries and geographical locations.
2. *Ideation and analysis:* Semi-structured collaborative working-sessions were held with mining, technical and research partners to understand the needs of the mining sector and inform the features of the "ideal digital tool". Structured focus groups were held with mining partners to understand how to merge the proposed assessment's features with the needs of the mines. From these engagements (n=12), a thematic analysis was conducted on the insights obtained and a draft digital tool was conceptualised. This digital tool was validated through additional feedback sessions with internal team members, mine representatives (heads of departments of innovation, training, learning and development) and technical experts (information, communication, and technology subject matter experts).

3. *Testing, iteration and refinement:* Using an iterative process, a pilot version of the digital tool was developed in collaboration with technical partners. An on-site pilot study of the digital tool was conducted with 51 participants (28 operators and 23 supervisors). An additional virtual pilot study was conducted which included nine managerial participants. The digital tool was refined in accordance with insights obtained from the pilot studies.

Ethics Approval

Ethics approval for this project was granted by the University of Pretoria Ethics Committee (Reference number: EMS149/22). The research complied with all the necessary ethics guidelines and requirements set by the Committee.

RESULTS AND DISCUSSION

After completing the desktop research, expert engagements and focus groups, a definition of digital leadership competence was decided upon. The most appropriate definition identified by the research team was that digital leadership competence is *the strategic use of a company's digital assets to achieve business goals* (Ritter, n.d.). Through pilot testing and stakeholder validation, the above definition by Ritter proved to adequately represent the digital leadership competence which could be applicable to the South African Gold and Platinum mining industry. The digital tool development process used this definition, along with previously defined digital terms, as a foundation to ensure the outputs of the tool aligned to the accepted definitions within the field of digital transformation. The research team additionally developed a digital construct spectrum as an amalgamation of key elements relating to the digital transformation and the representation of the progression of digital capabilities within the workforce.

Digital Construct Spectrum

Interacting with digitised technology systems implies that mine employees must subsequently possess the relevant digital skills to use technology and digital capabilities effectively. The effective use of digital skills creates value to operations by leveraging the correct skill sets for the utilisation of digital assets. However, digitisation has not occurred uniformly across sectors and mining operations. Therefore, it is imperative to consider a progression from a 'traditional mine' (not digitised) to a 'modern mine' (fully digitised). The understanding of this progression must be translated to the understanding of digital capabilities within the workforce. Using this understanding the digital construct spectrum (Figure 1) was created and validated with subject-matter experts and mining partners.

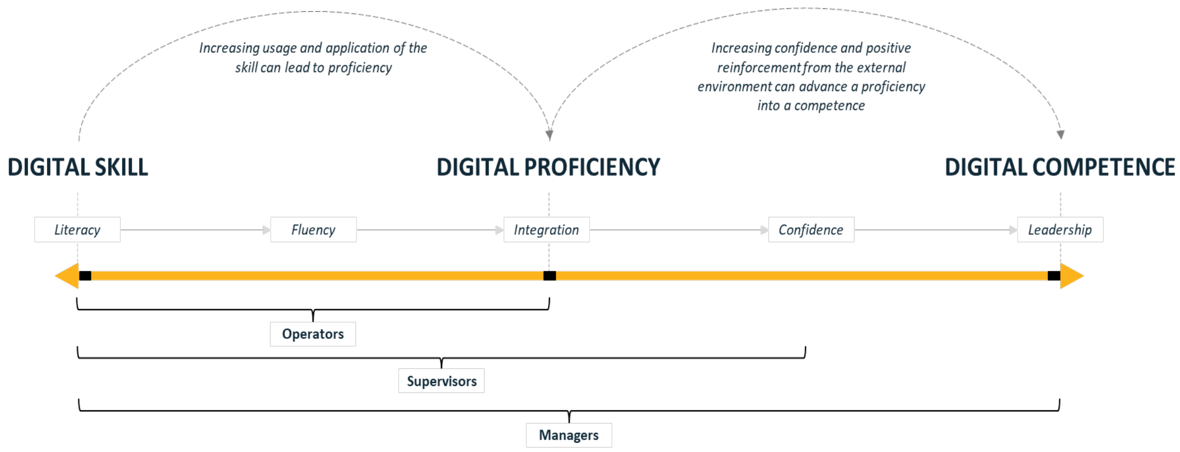

Figure 1. Digital construct spectrum.

The digital construct spectrum defines the boundaries between the four various constructs incorporated in the digital tool design through the following definitions.

1. **Digital skills:** The ability *to use a digital asset to perform an activity*; for example, using a cellular device to make a phone call, send a message, or look at the news (UNESCO, 2022; University of Nevada Las Vegas, 2022). Digital skills are associated with the construct of **digital literacy**, which refers to *the ability to navigate the digital world using reading, writing, technical skills, and critical thinking* (Microsoft, n.d.).

2. **Digital proficiency:** This refers to *the ability to understand, leverage, and integrate technology to increase personal and organisational efficiency* (AIHR, 2022). An example would be the storage of business contacts in a cellular device rather than having to commit each number to memory or place it in a Rolodex. Digital proficiency is associated with the construct of **digital integration**, which refers to a seamless utilisation of digital assets to increase the efficiency of a person's actions.

3. **Digital competence:** This is *the ability to use a digital skill to solve a problem or create value, and in being aware of which digital assets are ideal to perform a specific job function* (Deloitte, 2016). An example would be using a laptop to communicate to and coordinate a team to perform an operational role. Digital competence is associated with the construct of **digital leadership**, which refers to *the strategic ability to utilise a company's digital assets to achieve business goals* (Ritter, n.d.).

In practice, the digital leader is aware of the organisation's strategic objectives and comprehends how their job function contributes to such. Furthermore, the digital leader is able to explore how technology can be used to help their business in becoming more responsive to the needs of their stakeholders, and the ever-changing business requirements (Ritter, n.d.).

Tool Development

Engagements with the mining partner indicated that there is no digital leadership competencies gap assessment tool in the South African Gold and Platinum Group Metals mining sector. However, the majority of mines do possess leadership assessments. Hence, supplementing what exists was key.

The resultant digital tool consists of 67 assessment questions which are segmented between each digital construct according to the following quantities:

- General Introductory Questions = 5
- Digital Literacy = 12
- Digital Fluency = 12
- Digital Proficiency = 9
- Digital Confidence = 9
- Digital Leadership = 20

Operators are required to complete 38 questions; supervisors have a total of 47 questions to complete, and managers would complete the entire assessment, comprising of 67 questions.

The digital tool embodies 90% of the World Economic Forum's 2025 Future Skills report (World Economic Forum, 2020) as well as data safety, communication and collaboration, and strategy and value creation which contribute to the mine's ability to empower employees through professional and personal development. This can contribute to the overall mine's public image regarding employee relations - specifically responsible stewardship, operational excellence, and organisation effectiveness. In addition, the principle of 'grading', adapted from the European Framework for the Digital Competence of Educators (Punie, 2017) was included into the design of the digital tool. These inclusions contributed to gaining a deeper understanding of how each digital construct and question related to understanding the overall digital leadership competence of the mining workforce. A breakdown of the core assessment grades and associated digital capability and interpretation is described in Table II.

Table II. Digital Capability Assessment

Construct	Grade	Question Reference	Key Focus Areas	Interpretation (note low score is relative to baseline)
Digital Literacy	A1	6-14	- Technology use - Active learning	This grade relates to the employee's ability to use digital assets to communicate and learn. A low score would imply that the employee does not confidently type on digital devices and/or does not use utilise digital assets to learn.
	A2	15-17	- Data safety - Critical thinking and analysis - Flexibility and adaptability	These questions are evaluation-type questions based on the employee's general knowledge of digital security. A low score would relate to a lack of awareness in the discipline. In addition, this section aims to understand how the employee responds to change, and it is advised to review specific responses to understand how the employee truly feels about change.
Digital Fluency	B1	18-26	- Frequency of technology use	This selection of questions relates directly to how often the employee uses specific software or applications to perform a function. Note that many of these may not be required for the employee to perform their job. Therefore, it is essential to consider the actual job activities of that employee and whether the software tested is critical for them to perform their job.
	B2	27-29	- Communication and collaboration - Flexibility and adaptability	These questions relate to the employee's awareness of how and when to use technology to perform day-to-day activities. A low score would imply that the employee has not necessarily integrated their personal life with digital assets yet.
Digital Proficiency	C1	30-32	- Technology use	This grade relates to employees' ability to integrate their personal or professional activities with technology for optimal results. A low score would imply the employee still lives a relatively '*low-tech*' life.
	C2	33-38	- Critical thinking and analysis - Flexibility and adaptability	This section aims to understand if and how employees use the internet to obtain information. Once that information is obtained, how do they then make sense of it in relation to their specific job function within the organisation? Furthermore, the section aims to understand the psychological nature of the employee and how they perceive themself regarding the digital transformation happening around them.
Digital Confidence	D1	39-44	- Technology use - Communication and collaboration	The digital confidence section tries to understand how capable employees believe they are when using digital assets to perform specific job activities. A low score would imply that the employee is not confident using the specific applications to perform their job.
	D2	45-47	- Active learning - Flexibility and adaptability	This section aims to understand how employees proactively use digital assets to learn and subsequently apply those learnings to their jobs. In addition, this section attempts to understand how the employee responds to change within their job function. A low score would imply that the employee does not actively learn and apply new ways of doing things to their job activities, nor are they willing to.
Digital Leadership	E1	48-56	- Critical thinking and analysis - Creativity - Strategy	These questions aim to understand the level of critical thinking with digital assets the employee utilises to understand and interpret information. Relate that information to the organisation's objectives. Plan a course to achieve those objectives using the information and human capital at their disposal. Lastly, setting clear goals to measure, monitor, and evaluate the outcomes of their decisions. A low score would imply limited utilisation of digital assets to perform the steps above.
	E2	57-67	- Communication and collaboration	This section aims to understand how employees lead and influence across digital channels and whether they are willing

			- Leadership - Flexibility and adaptability	to adapt to the digital transformation around them.

(Source: Mahadeo et al.*, 2023, adapted from Punie, 2017)*

Key features of the tool include:

- 67 questions for different roles in the organisation – operators, supervisors and managers.
- Consent form for end users and explanation that submissions are anonymised, and no data is shared outside the key group of mine managers and administrators.
- Questions consist of multiple choice, checkboxes, drop-downs, and open texts.
- Resource Library to act as a repository of useful information on digital constructs and digital leadership.
- Contains defined features for specific functions.
- Contains analytics and downloadable data files to provide information on the use of the tool by end users.
- All reports for the mine's main operations can be managed from a central point with the super administrators.
- This is a web-based tool available on a mobile device e.g., smart phone, tablet, or laptop.

Through a series of four iterations, different elements of the tool were built sequentially:

- Core survey for end user with key questions and response options.
- Information resources and glossary terminology examples.
- Back-end administrator and super administrator functionality for administering the survey, managing users, managing the data sets and compilation of analytic reports.
- Dashboard with aggregator analytic reports for core questions and robot summary reports for managers to view.

The reporting outputs of the digital tool consists of graphical representations (Figure 2) and an interpretation matrix.

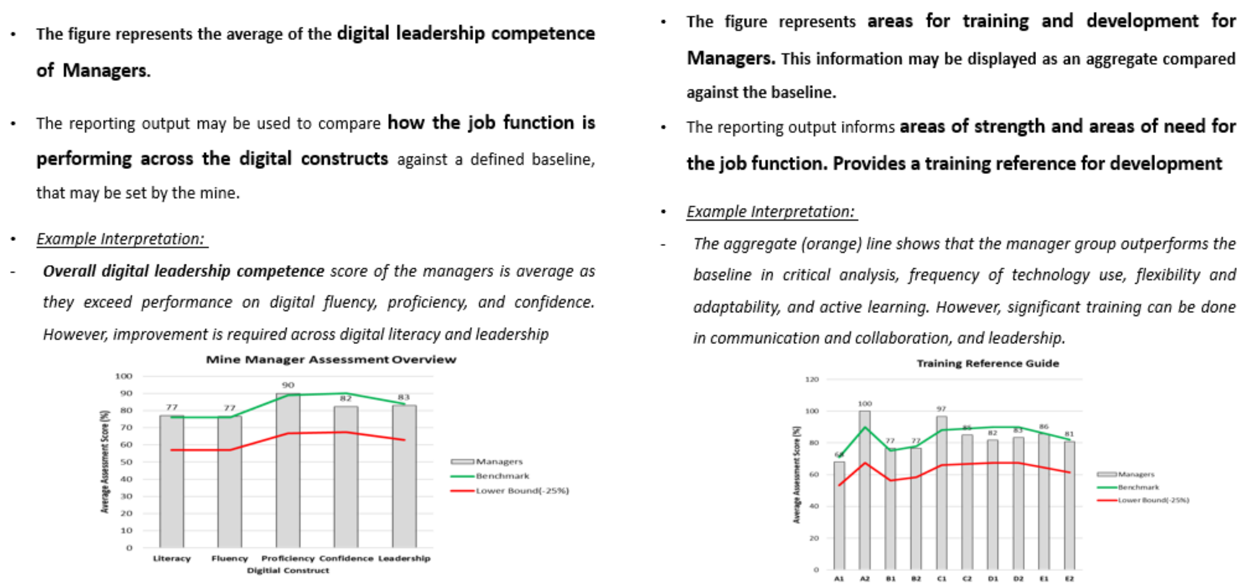

Figure 2. Graphical representation of manager outputs (example).

Pilot Findings
The pilot testing of practical application consisted of both in-person and virtual sessions. The in-person session was conducted at a platinum mine and included operators and supervisors. The virtual pilot was conducted with managers only. Notable insights and comments from the open-ended qualitative questions received during the pilot programme included the following responses:

- The majority of participants found that the language in the digital leadership competency assessment was moderately easy to understand.
- A minority of participants indicated that the questions should be simplified to understand and interpret more accurately.
- Participants highlighted the need to shorten the assessment to reduce the time required to complete it. Generally, the survey could be completed on average within 25 minutes for operator level and an average time of 40 minutes at managerial level.
- The survey is useful in improving the workforce's understanding of digital leadership competence and what is expected of them regarding digital capabilities.
- The survey would be better suited as an online form so that mobile devices can be used (for context this pilot study used a paper based version during the session).
- The majority of participants mentioned that they are most likely to complete the assessment via a mobile device.
- For the in-person session, a translator was on hand to interpret, which contributed to participants being able to follow the questions in a facilitated manner.

The feedback received pertains to the user experience (e.g., gained a deeper understanding of the requirement of digital leadership competence) and the language (e.g., translation was a significant benefit). The findings were included in the final version of the digital tool. Overall the utility value of the digital leadership competency assessment tool provides the mining industry with four calibrated constructs, assessment grades and interpretation matrix which can be used by learning and development practitioners to assess their workforce and provide baseline determinants.

Transfer to Industry
Adoption of the digital tool may enable mines to empower employees through professional and personal development, through digital leadership capability gap identification. The intended short-term outcome is the potential to contribute to employee relations, specifically regarding responsible stewardship, operational excellence, and organisational effectiveness. In the long-term, the digital tool may facilitate the introduction of Fourth Industrial Revolution and just transition (e.g. green, lower carbon technologies, mechanisation, or automation) technologies, which would enable healthier and safer mining extraction and production. In doing so, the envisaged impact on the mining industry is geared towards supporting the social element of the ESG agenda by:

1. Establishing a digital leadership capability baseline for mines/the South African mining industry.
2. Prompt skilling, upskilling or reskilling potential for the mining workforce to prepare for a more digitised mine.
3. Supporting job sustainability for the mining workforce.
4. Encouraging capacity building and empowerment for digital transformation.
5. Supporting preparedness to drive and lead digital transformation.
6. Allowing for inclusion of stakeholders in digital transformation.

The adaptations from the user-centred design approach to the digital tool have increased the usability and practicality of the assessment, which may be applied to a wider target audience than previously considered (e.g., not only mining but manufacturing, fabrication, agriculture, and automotive).

Figure 4. User-guide for the Digital Leadership Competencies assessment digital tool.

The collaboration and co-creation resulted in a guideline which is essential in disseminating the digital tool to mining operations and relevant adjacent industries. The user guideline, with accompanying video (Figure 5), has been designed to assist users to familiarise themselves with the implementation of the digital tool and has instructions for the IT administrator to embed the tool in the mine's information management system, and guide for users to use the tool and administrators to administer the tool rollout and analytics dashboard. Instructions for administrators includes the production of analytical reports to provide time-based reports to aid managers. The data and trends via assessments at different intervals can assist the management team to prioritise further training interventions for enhancing the digital capability of the three groups of operators, supervisors and managers.

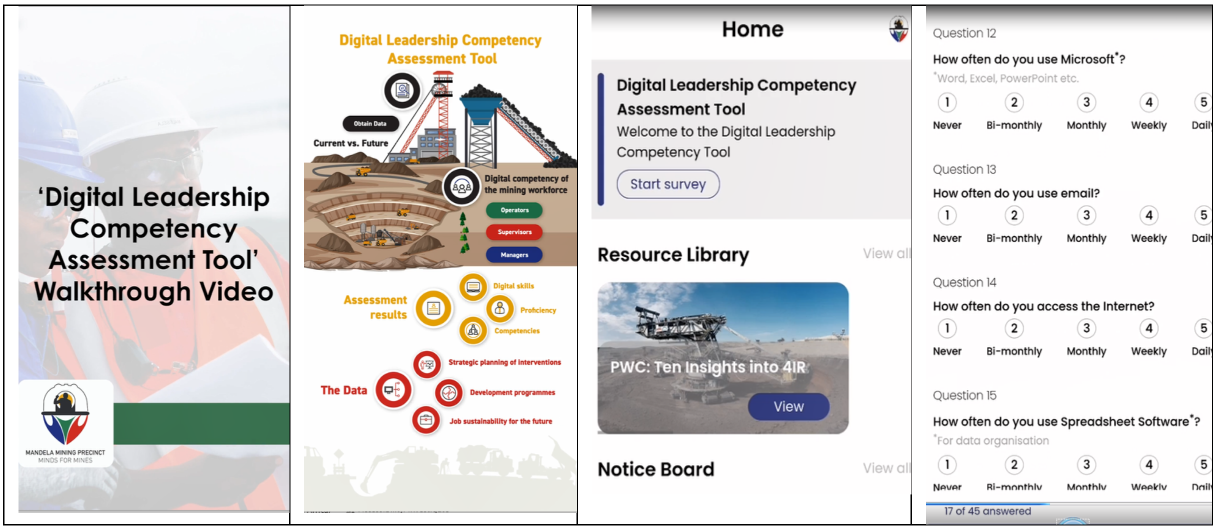

Figure 5. Screen capture: tutorial video.

The final digital tool and user-guideline with accompanying video are accessible on the Mandela Mining Precinct website.

CONCLUSIONS

The need for this project arose from a gap identified in the mining industry, in that there is currently no digital leadership competency assessment in existence within the South African Gold and Platinum Group Metals mining sector, despite the observation that many mines do possess general leadership competency assessments. Further, there is no commonly accepted definition of digital leadership competence, nor baselines to support digital transformation in the mining industry. A further variance is the differences in the state of modernisation amongst different operations. Thus, any digital transformation strategy is highly dependent on the current infrastructure and level of digital transformation within each mining operation. This further influences the level of digital competency that each mining operation will require for different levels of the workforce.

Based on the above considerations, a digital leadership competencies assessment tool was developed. The process of reiteration leading up to the digital development of the tool followed the Stanford Design Thinking approach of ensuring a user-centric design, which enabled the development of an assessment tool that is generalised enough to measure digital leadership competence within mining operations.

In summation, the Digital Leadership Competencies assessment application fulfils three primary objectives of the project objectives:

1. Validates and measures digital leadership competence, with specific consideration to supervisors, operators and managers;
2. Is applicable to the South African Gold and Platinum Group Metals mining sector and associated workforce; and is
3. Aligned with global standards.

The tool supports gap identification of digital leadership competencies to enable employee development towards driving of digital transformation in mining.

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Digital twin enabled augmented reality application for remote assistance

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To enhance the effectiveness of remote assistance, this paper presents a solution architecture that integrates a digital twin (DT) with augmented reality (AR). The DT offers a single source of data related to design, configuration, historical, and real-time operational data of the represented physical entity (e.g. instrument or system), which provides the basis for the bi-directional interaction between the remote assistant and the on-site technician. This interaction is then enriched through an AR experience for the on-site technician and interactive user interface for the remote assistant, which enables multi-modal communication and information exchange.

INTRODUCTION

Effective remote assistance in the mining industry requires structured, multi-modal communication to convey instructions for the repair or maintenance of systems or instruments. This multi-modal communication requires the combination of different, complementary technologies. Relevant technologies have seen recent advancement within the ongoing fourth industrial revolution, such as the Internet of Things (IoT), augmented reality (AR) and digital twins (DTs).

Industry 4.0 is the new industrial model that is characterised by intelligent, virtual and digital performance. This is an advanced manufacturing model that includes factory-wide integration. The previous industrial model was based on digitalisation, whereas Industry 4.0 increases productivity through 'smart factories' – enabled by integrating the production process with the internet by means of sensors and artificial intelligence (Schwab, 2016).

The design principles of an Industry 4.0 system consist of decentralisation, virtualisation, interoperability, modularity, real-time capability and service orientation (Hermann, Pentek, Otto, 2015). Decentralisation refers to machines as parts of a system, being independent and making decisions on their own, rather than using one central device that makes decisions hierarchically. This provides a flexible design and makes maintenance much easier (Roblek, Meško, Krapež, 2016). With machine-to-machine monitoring, virtualisation is achieved with a virtual (or digital) twin that can be constructed using the sensor data and linking it to the physical machine. Interoperability allows intelligent systems to autonomously exchange information and actions, as well as control each other independently. Modularity is what allows the system to adapt in an ever-changing world – modules can simply be swapped out without having to redesign the whole system for one improvement to be made. The real-time capability of Industry 4.0 allows software to adapt to the production needs of a process.

Finally, Industry 4.0 requires service orientation, which enables stakeholders to use services, and have access to relevant products and information, over the internet (Ortiz, 2020).

Cyber physical systems (CPSs), in combination with IoT, have multiple benefits for Industry 4.0. Hasan et al. (2022) defines a CPS as a system that fully integrates a physical process with computation. This is done by feedback loops, where the predictions are based on the behaviour of the real system. In a CPS, the communication is bi-directional between the physical and virtual components. For this to work, the system must be embedded – meaning that the system is a combination of components with memory and other peripheral interfaces.

DTs are also considered a key enabler for Industry 4.0. A DT replicates a physical system in a digital world – mimicking the behaviour and physical changes of the system. A DT consists of three parts: the physical system, virtual system and connected data. The connected data is what allows the virtual system to mirror, emulate and monitor the physical system (Tao et al., 2018). DT technology has been implemented in multiple domains, such as manufacturing, aerospace and construction (Hasan et al., 2022). In these applications, DTs have mainly been used for monitoring, prototyping and training.

AR is a technology that merges real and virtual worlds. In AR, digital objects can be seen in a real world (Jetter, Eimecke and Rese, 2018). This technology is not limited to a device or visual information and has been used in medical visualisation, maintenance and repair, robotics, military, as well as in entertainment. According to Jitter, Emimecke and Rese (2018), AR can help to overcome the lack or absence of maintenance personnel. Rebbani et al. (2021) found that another useful application for AR is remote assistance.

This paper presents an architecture for a DT-enabled AR application for remote assistance. The architecture uses the DT of a physical system, which can provide relevant design information, models and operational data of the physical system, to facilitate and enhance the interaction between the remote assistant and site technician in remote assistance scenarios. To better support the site technician, an AR application – served by the DT – provides an enriched, multi-modal experience.

The paper first provides a review of related work on DTs and reported integrations of DTs with AR. Thereafter, the architecture for the DT-enabled AR application is presented, followed by the description of a illustrative case study of the application in mining. Finally, the paper concludes with a summary of the contribution and discussion of future work.

RELATED WORK

Digital Twins

The "Digital Twin" term originated at NASA in 2012 and was described as an integrated system of multiple components that are simulating a physical system (Fuller et al., 2020). This is done by using the best available data from the system, which can be sensor data, a physical model or historical data. Using this data, the DT will mirror its corresponding physical twin (Fuller et al., 2020). The implementation of a DT requires automatic, bi-directional data exchange between the DT and its physical twin, which distinguishes a DT from a Digital Shadow or a Digital Model (Kritzinger et al., 2018). However, some DT researchers do not require autonomous data flow from the digital to the physical twin, but employ DTs to support decisions by humans that indirectly affect the physical system (Human C, Basson AH, Kruger K, 2023).

DTs have seen rapid advancement and adoption Industry 4.0. DTs require a digital platform with multiple connected devices that are also connected to the internet. However, it is typically intended for the physical system to be able to operate independently, with known control strategies, before the addition of the DT (Fuller et al., 2020).

Digital Twin Architecture

Redelinghuys, Basson and Kruger (2020) developed an architecture for implementing a DT, called the Six-Layer Architecture for Digital Twins (SLADT). This architecture describes the functional layers of a

DT and the protocols required to effectively communicate between layers. The SLADT architecture is presented in Figure 1.

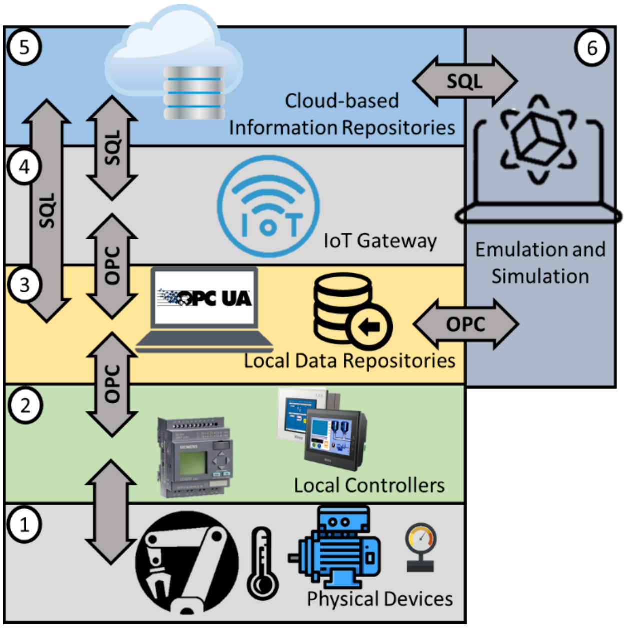

Figure 1. Six-Layer Architecture for Digital Twins (adapted from Redelinghuys, Basson and Kruger (2020))

The first and lowest layer of this architecture is the physical device. This includes components of the system as well as measuring instruments. The second layer is responsible for controlling the hardware devices in the first layer. Controlled parameters or results of the system performance are stored in a temporary, local data repository in layer 3 of the architecture. If the third layer is connected to the internet, data can be used by DT services in layer 6 or, using an IoT Gateway (layer 4), the data can be stored in a long-term (cloud) repository in layer 5. Layer 6 services also have access to stored data in layer 5. It is clear from the architecture that the information flow is bi-directional between the layers (Redelinghuys, Basson, Kruger, 2020).

SLADT was subsequently extended to include aggragation, named SLADTA (Redelinghuys, Kruger, Basson, 2020b). To enable greater value addition through DTs, and to support the integration of DTs to external digital systems and services, SLADTA was integrated in a greater service-oriented architecture) (Kruger, Human and Basson, 2022), as illustrated in Figure 2.

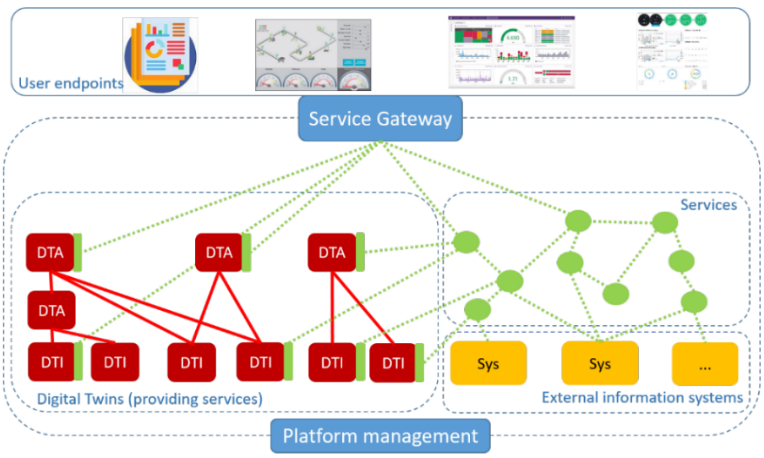

Figure 2. Architecture for integrating DTs with services (Kruger, Human and Basson, 2022).

In the architecture in Figure 2, DTs maintain a reflection of reality and can offer services to external users/systems based on their data and models. The architecture also makes provision for services in a services network (which is conceptually removed from DT services), which represents artificial aspects dictated by user requirements (as opposed to the reflection of reality). The DT services and network services populate dashboards and reports as user endpoints. The services network has no specific hierarchy; however, some services may aggregate information from other (DT or services network) services. The bi-directional flow of information between the user and the system is managed by a service gateway.

Augmented Reality with Digital Twins

The addition of AR with DTs could provide an environment where digital data is available in the physical world. Ong and Nee (2021) have developed a method for remote monitoring of systems using AR in combination with digital twins.

Their digital system design is very similar to that of Figure 2. The user can interact with the DT through the AR application. The information in the AR application is presented to the user through the DT. The user will then be able to monitor and control the real-world system by making changes to the DT.

This system can only function if all the devices are equipped with the correct sensors and software, and these different systems can communicate with each other. Key enablers include:

- **Real-time data collection**: The physical device should be continuously measuring and monitoring the system while operating.
- **Historical data logging**: The physical device should store all historical data. This is essential for analytics and event identification.
- **Digital model of the system**: : A CAD model of the system is required as this would enable the physical properties can be added to the digital twin, which would allow for additional testing like finite element analysis on the various components.
- **Computation engine**: The simulation and data analyses are extremely demanding and would require large amounts of computing power.
- **AR user interface**: Software should be installed on a mobile device to obtain data from the digital twin.
- **AR interface development**: AR requires both hardware and software. To integrate these two, development tools are required.

ARCHITECTURE

Architecture Overview

The architecture presented here for a DT-enabled AR application for remote assistance is illustrated in Figure 3. The architecture is based on the architecture in Figure 2, with DT and DT services components and a services network that serves the two user endpoints (i.e. remote assistant and site technician).

Figure 3 represents the simplified case where only one DT is present, but this single element can be replaced by an organisation of DTs for more complex cases (as is provided for in Figure 2). The small yellow circles in Figure 3 represent examples of services – those located within the same container as the DT are classified as DT services, while the others are services within the services network component of the Figure 2. The connections between services indicate the various service interactions. Various services provide information – as obtained from the DT – to the two endpoints, serving the Remote Assistant graphical user interface (RA GUI) and the site technician AR application.

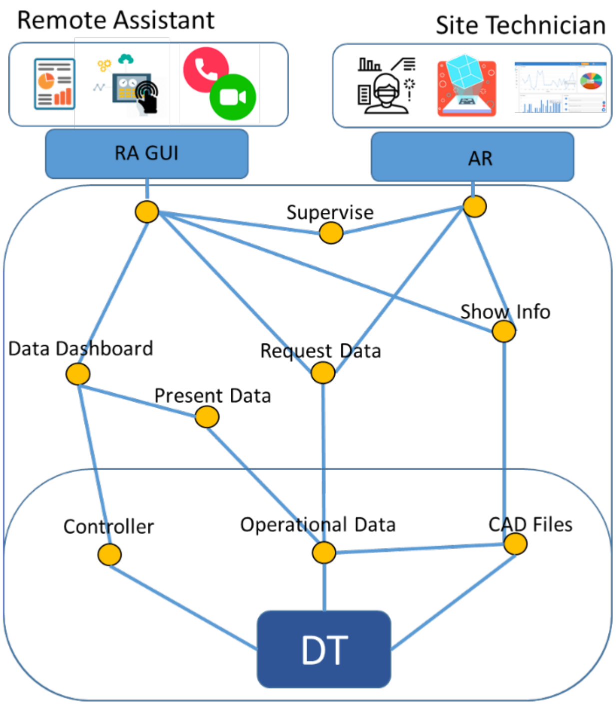

Figure 3. Service network that integrates the DT for remote assistance.

Digital Twin and Digital Twin Services
DTs are used to reflect reality, which results in a digital system that replicates and represents the real world system. A DT service, on the other hand, presents the user with additional information. This can be analytics of data or other services to access data. The DT should only focus on data encapsulation, whereas DT services pull data from the DT and does not alter the DT. In this way, a DT can be used for multiple applications through the services that it provides, without changing the way the DT represents the physical twin.

Services
The services within the services network are developed to serve the user requirements for specific application, by receiving requests from and providing information to user endpoints. Since the DT and DT services are intended to be application agnostic, the services not coupled directly to the DT must access, transform and process the DT data – accessed by means of the DT services – in a manner that serves the user endpoints.

User Endpoints
The user endpoints are the interfaces where the system can receive and serve requests from users. The nature of such interfaces can be diverse, e.g. GUIs, dashboards, reports, emulations, etc. While Figure 2 can accommodate multiple, diverse user endpoints, the architecture in Figure 3 considers a simplified case where only the endpoints of the remote assistant and site technician are served.

Site Technician AR Application
The site technician user endpoint should allow the site technician to effectively communicate with the remote assistant. This communication should be bi-directional and the remote assistant must be able to give feedback on operations. This communication can be enriched with data contained in the DT, which the remote assistant can present on demand. The presented data allow the remote assistant to overlay the information in the site technician’s field of view. Other overlays may include annotations in the site technician's field of view (e.g. circle/point/draw on component/instrument).

Remote Assistant GUI
The remote assistant user endpoint allowes the remote assistant to communicate with the site technician while having access to all the DT information. The GUI enables the remote assistant to interface with the DT, communicate with the site technician and view and annotate the site technician's field of view.

CASE STUDY

This section presents a case study that demonstrates how the presented architecture for a DT-enabled AR application can be deployed in the mining context. First, the case study context is described. Thereafter, the implementation of the architecture for the case study is discussed.

Case Study Context

The standard practices that are currently in place to assist technicians on mine sites are considered to be very limited. For Mintek, a mining company in South Africa, it was found that during breakdowns or faults, the site technician would have to phone the specialist (i.e. remote assistant) to assist with the fault in order to get the system up and running again. These calls are usually ineffective and, subsequently, require the specialist to visit the site to ensure that the system responds as intended. This process can cause delays in operation, as specialists have to travel to the sites in remote locations all over the world. The architecture presented in the paper is applied in this case study to improve the effectiveness of remote assistance for repair or maintenance activities.

The physical system used in this case study is the *Cynoprobe* measuring instrument. As part of the gold or copper recovery process, the ore slurry is fed to leaching tanks where cyanide is used as the lixiviant to leach the metals from solution. Cyanide performs this extraction process by forming a complex with the gold or copper (it will, however, form a complex with most base and precious metals) and this complex is then adsorbed onto activated carbon, which goes for elution and electrowinning to obtain the final, purified product. The Cynoprobe is a measurement instrument that measures the concentration of cyanide, in parts per million, in the leaching tanks. This value is important for control purposes, as the concentration of cyanide must be high enough to obtain the best possible metal yield, but must also not exceed a certain concentration as it is highly toxic. This measurement is also required in order to add the correct quantity of lime (CaO or $Ca(OH)_2$ when in solution), which increases the pH in the leach tanks to above 11, preventing the formation of gaseous hydrogen cyanide.

The Cynoprobe consists of two cabinets – the wet and dry 'boxes'. The wet box consists of multiple valves, measuring cell, pump and stirrer. The dry box consists of all the electrical devices that make the measurements, control the valves as well as send and store the measurements. This measuring process is controlled by a programmable logic controller (PLC) and the human machine interface (HMI). The location of the Cynoprobe relative to the tanks will have an impact on how the system runs; as such, the HMI is used to calibrate the Cynoprobe on site.

Implementation

In the case study, the site technician was equipped with an AR device that can be operated hands-free – specifically, the Microsoft Hololens II. This device allows the site technician to communicate with the remote assistant, as well as share their field of view. The remote assistant had access to a GUI on their personal computer. Through the GUI, the remote assistant was able to monitor and guide the site technician during a repair or maintenance task. The remote assistant can provide the site technician with information that is stored in the DT, and can annotate the technician's field of view.

Digital Twin
The DT for the cynoprobe was implemented according to SLADT. The implementation of each of the six layers was performed:

- Layer 1 (physical device) – various sensors are installed on the Cynoprobe that measure cyanide concentration, pH, valve positions and fluid levels ton the physical instrument.
- Layer 2 (local controller) – a PLC that controls the instrument and captures all sensor data, with an HMI device for display and operator input, serve as the local controller for the Cynoprobe.

- Layer 3 (local data repositories) – data from the instrument is stored on an EWON edge device that is connected to the PLC and HMI over Ethernet.
- Layer 4 (IoT gateway) – the IoT gateway executes on the EWON edge device, which is connected to the internet and sends processed instrument data to the cloud repositories using MQTT.
- Layer 5 (cloud-based repositories) – the cloud storage used for this application is Microsoft Azure.
- Layer 6 (services) – The emulation was done using Unity in combination with Azure functions and Azure DTs. Services like analytics used Power Bi with data stored in Layer 5.

Services
Figure 3 indicates the various services – related to the DT and services network – developed for this case study. The following DT services were developed:

- Controller – a service to view, navigate and change the HMI of the physical system via the DT.
- Operational Data – a service to view and extract data from the DT, related to system configuration, data sheets, user manuals, service history, operation history and real-time operation.
- CAD Files – this service provides access to DT data such as CAD models, operational emulations or maintenance steps.

The following services were developed for the services network:

- *Present data* – this service transforms the operational data, more specifically the real-time data and historic data, into graphs and reports.
- *Data dashboard* – this service combines all other data fields into a single interface that handles all remote assistant GUI interactions.
- *Request data* – this service extracts data, required by the user endpoints, from the DT through interaction with the DT services.
- *Show info* – this service works in the same manner as the request data service, but instead retrieves model emulations from the DT for maintenance steps.
- *Supervise* – this service allows the remote assistant to monitor the site technician's field of view, by maintaining a live video stream from the AR device.

User Endpoints
The site technician is aided with digital content overlaid in their field of view. This digital content could be a display of maintenance steps or an emulation of the complete system. In Figure 4, a model of the complete system is placed in the site technician's field of view. This is used in situations where the technician requires some training or knowledge before going on site to do maintenance or repairs. The remote assistant has information from the DT and may identify the problem and work through the solution before the site technician goes to the physical instrument.

Figure 4. Model of the instrument placed in the site technician's field of view.

Figure 5 shows another instance of digital information overlaid in the site technician's field of view. This view, as displayed by the AR headset, shows how the remote assistant can insert a digital object into the site technician's field of view. This digital object explains the process of replacing the filter sock through an emulation. The technician would simply replicate these maintenance steps while monitored by the remote assistant. Once the process is completed, the remote assistant approves the process and removes the digital object from the technician's field of view.

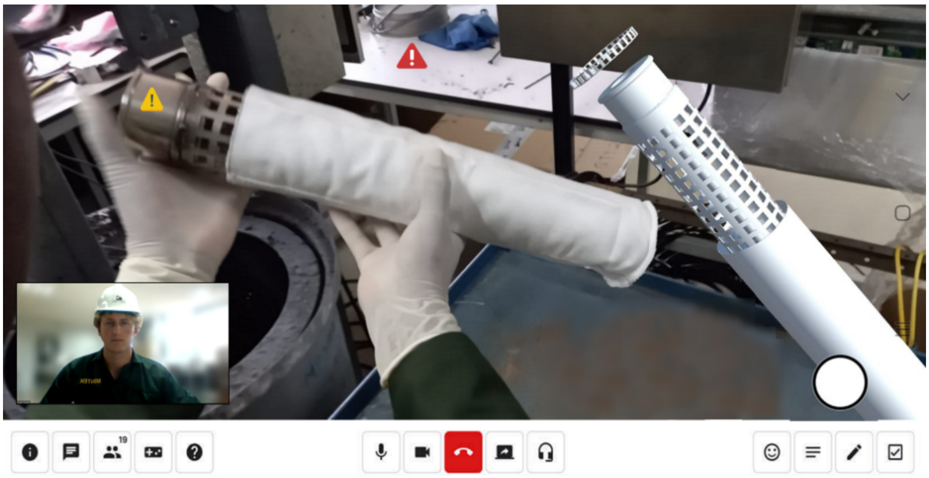

Figure 5. Remote assistance with maintenance steps.

The remote assistant GUI consists of multiple windows, as shown in Figure 6. One of the windows is the live stream of the site technician's field of view. Another window is real-time operational data from the physical system, as well as historic data on maintenance and operations.

The remote assistant can access all services and data in the DT from this interface. From the GUI, the remote assistant can log into the controllers and make changes to the system when required. This GUI can also be used to view the controller and to see if the software is up to date.

A tools section, as indicated in Figure 6, aids the remote assistance process by providing the remote assistant with tools to annotate the site technician's field of view. When the site technician has trouble locating an item/component, or does not know what the remote assistant is referring to, the remote assistant can simply use the tools to draw attention to the component being discussed.

The remote assistant can also select from multiple emulations that are provided by the DT and place them into the site technician's field of view when required. The emulations could be maintenance steps or even emulations of how the system should respond.

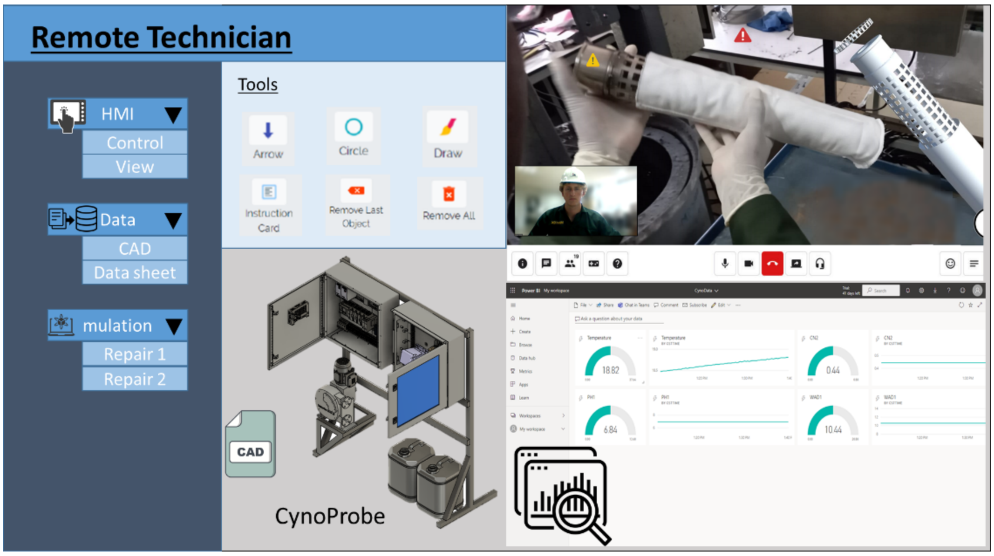

Figure 6. Remote assistant GUI.

DISCUSSION

Remote assistance on real world systems, built on a DT, allows for greater integration of data, tools and knowledge. Remote assistance is achieved by providing DT services that access data, translate it, and provide users with the support tools required.

Importantly, DTs can offer functions/applications beyond remote assistance (all the implementations reported in literature on other applications). Using DTs for remote assistance adds more value to the investment of developing DTs. All these applications are achieved through DT services, where the DT serves as the basis of all implementations.

Finally, AR can be an excellent medium for enriched technical communication, and allows for monitoring/supervision. The enriched technical communication will likely improve the probability that repairs and maintenance tasks can be performed successfully through remote assistance, which will decrease the cost and time involved in the travelling of specialists.

CONCLUSION

Standard practices for remote assistance in mining are not always effective, resulting in costly travel of specialists to remote sites to do repair or maintenance tasks. This paper presented an architecture for a DT-enabled AR application for remote assistance. The architecture utilises the DT of the physical system, which encapsulates data, models and services related to the physical system, as a basis for the remote assistance interactions and information exchange. Two user endpoints – the remote assistant GUI and site technician AR application – are served by services that can access, process and provide information from the DT.

The architecture was implemented in a case study that focussed on the mining context. The case study implementation entails the development for the DT of a physical instrument, the development services to support remote assistance, and the design of the user interfaces.

In future work, the services to support enhanced communication and an enriched AR experience will be further explored. More testing is planned to evaluate the ease of use of the application, as well as metrics related to latency, bandwidth and hardware requirements.

ACKNOWLEDGMENT

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I am currently working for Mintek in Johannesburg where I'm designing and building small-scale prototypes of functional mining instruments. Thus far, these prototypes have been displayed at the Mining Indaba in Cape Town as well as at the Future Minerals Forum in Saudi Arabia. My work focusses on industry 4.0 and combining new technologies such as loT, Augmented Reality and Simulations to build automated and integrated systems on mining instruments.

An integration platform for smart, integrated mining

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The mining sector frequently faces the two-fold challenge of integrating data from various sources, and integrating various decision makers and decision-making processes that utilise the data. This paper presents an integration platform to support real-time monitoring, coordination and decision making in mining contexts. The integration platform is based on a *Holonic Systems* approach and is implemented using the *Biography-Attributes-Schedule-Execution* architecture. The functionality of the platform is illustrated by means of a case study implementation, which integrates sensors, human and non-human resources, business processes, and decision maker interfaces.

INTRODUCTION

The mining sector frequently faces a two-fold challenge: integration of data from various sources, and integration of various decision-making processes that utilise the data. Even when mines adopt sophisticated systems and solutions to address this challenge, the functionality and data frequently remain isolated within *silos* – with little provision and capability for integration.

As per the vision of the fourth industrial revolution, new opportunities for value-generation lie within the integration of data, systems and technologies. To achieve this integration, development should be focused on two aspects: firstly, the functional and data silos have to be fused in a structured and reconfigurable manner; and, secondly, decisions and reactions to the data need to be effectively communicated and executed for the value to be realised. Furthermore, when human workers directly execute mining processes, it presents particular challenges – to obtain data from the humans, to use data-driven systems to direct their actions (in response to decisions made at higher organisational levels), and to aid their decision-making in their immediate context. These challenges are acute when the workers have low skill levels and where their actions significantly impact safety and productivity.

This paper presents an integration platform to support near real-time monitoring, coordination and decision making in mining contexts – specifically, where human workers play an integral role. The development of the platform, using the *Holonic Systems* approach and *Biography-Attributes-Schedule-Execution* (BASE) architecture, is described. The functionality of the platform is illustrated by means of a case study implementation, which integrates sensors, human and non-human resources, business processes, and decision maker interfaces.

The developed integration platform promises to unlock new opportunities for value-addition through the integration of various aspects of mine operation and management and, specifically, the integration and information management of mine workers – thereby improving situational awareness and supporting reactive and proactive decision-making.

The paper presents some related work, to place the presented research in context. Thereafter, the design of the integration platform is presented, the case study implementation is discussed, and, finally, a conclusion is offered.

RELATED WORK

This section presents a brief review of literature on software systems, connectivity solutions and system integration applications in mining. The related work includes underground and surface-level mining case studies. Furthermore, this section presents research related to Industry 4.0 technologies and concepts. Lastly, background is given on the BASE architecture, which is used to implement the integration platform presented in this paper.

Software System and Data Integration in Mining

Bassan, Srinivasan, Knights, *et al.,* (2008) proposed the *mine of the future* for 2025, which included smart mining systems designed to automate business processes and decision-making, using advanced analytics tools. This idea relied on the improvement of system integration technologies and virtual collaboration systems to provide a 'network effect' between 'isolated' systems so that the overall goals of the entire system are achieved. To achieve such a future, amongst other reasons, Industry 4.0 (I4.0) concepts and technologies from manufacturing have begun coming into effect in the mining industry (Lööw, Abrahamsson & Johansson, 2019).

Enabling technologies for I4.0 include the Internet of Things (IoT) devices and communication protocols, big data and analytics, autonomous robots, system integration, augmented reality and Cyber-Physical Systems (CPSs) (Bigliardi, Bottani & Casella, 2020). CPSs aim to connect the physical and virtual world using various networking, computing, sensing, data storage, and software technologies (Pivoto, de Almeida, da Rosa Righi, *et al.*, 2021). A prominent architecture for CPSs is the 5C's architecture, which defined smart connection, data-to-information conversion, cyber, cognition and configuration layers (Lee, Bagheri & Kao, 2015). Related work on CPSs in the mining industry has relied on IoT advancements in wireless sensor networks (WSN), wireless area networks (WAN) and communication protocols, such as ZigBee.

Nikolakis, Kantaris, Bourmpouchakis, *et al.,* (2020) developed a CPS to support smart on-demand ventilation control for underground mining. The CPS included sensors that measured air quality, temperature and humidity in the mine environment and actuators for the ventilation fan control. Additionally, the networking was achieved through implementing a long-range wireless communication network, which utilised IoT nodes installed throughout the mine tunnel. This case study evaluation indicated that the CPS reduced the energy consumption of the ventilation system.

A recent review by Molaei, Rahimi, Siavoshi, *et al.,* (2020) of IoT and its application in mining has argued how IoT devices and networking have:

- Improved the resource utilisation of mining fleets.
- Improved the visibility and control of mining operations.
- Aided business processes.
- Aided predictive analysis to reduce breakdowns and operating costs.
- Improved mine worker safety.

Research into software systems and data integration in mining has generally orientated itself around the application of smart sensor devices and WSN to improve the traceability of mining operations and improve safety in mining. The use of these IoT devices and systems for specific use cases, such as detecting hazardous gasses or positioning equipment, has shown benefits. However, there is no integrated infrastructure to support data from different IoT systems across applications (Molaei *et al.*, 2020).

Mineworker-related Systems and Technology

A key aspect of digital transformation in mining is ensuring that digital systems and equipment are effectively integrated with people (Ulewicz & Ingaldi, 2022). Human Cyber-Physical Systems (HCPSs), as defined by Yilma, Panetto & Naudet (2021), is *"a system of interconnected systems (i.e. computers, devices and people) that interact in real-time, working together to achieve the goals of the system"*. HCPS concepts, such as the Operator 4.0 model developed by Romero *et al.*, (2016), have since been translated to the mining industry – described as the Miner 4.0 (Lööw *et al.*, 2019).

Lööw *et al.,* (2019) described a Miner 4.0, supported by I4.0 technology, as being:

- *Smarter* - having intelligent personal assistants for interfacing with information systems and machines.
- *Collaborative* – capable of reducing the miner's workload by collaborating with other machinery or humans.
- *Healthy* – using wearable sensors and systems for monitoring health-related metrics.
- *Analytical* – having decision-support systems which analyse data captured from the environment.

Progression towards a smart and integrated miner, or Miner 4.0, can be seen in the recent application of I4.0 technology for mine workers. These technologies are generally related to position tracking and health and safety monitoring. Such technologies include the use of smart wearable devices, as well as utilising IoT networking technology for data communication.

Singh *et al.,* (2022) developed an IoT-enabled helmet to improve the health and safety monitoring of mineworkers underground. The smart helmet utilised various gas sensors, accelerometers, GPS and IoT connectivity to aid in the early detection of hazardous conditions for the mine worker. This real-time smart helmet device is able to alert the mineworker of hazardous gas exposure, high temperature, early fire detection and silicosis dust particles. Other wearable developments include a smart jacket that can monitor the miner's pulse rate, global position, temperature and humidity exposure and can transmit alerts along the network in the event of an emergency (Ananth, Thenmozhi, Vadakkan, *et al.*, 2022). Baek & Choi, (2019) developed a low-cost proximity warning system for mineworkers and equipment underground, using smartphones and Bluetooth beacons. These developments demonstrate the application of smart devices and IoT networking to implement a mineworker safety system.

The BASE Architecture

The Reference Architecture Model Industry 4.0 (RAMI 4.0), which aims to support I4.0 integrations, describes six interoperability layers: *business*, *functional*, *information*, *communication*, *integration* and *asset* (Zezulka, Marcon, Vesely, *et al.*, 2016). The *asset* layer represents the physical world which is connected to the virtual world through developments in the *integration* layer. A I4.0 component model, developed as an extension of RAMI 4.0, prescribes a digital administration shell for each physical *asset* that must contain specific information and enable standardised communication between administration shells.

The BASE architecture, developed by Sparrow, Kruger & Basson (2021), guides the development of such *digital administration shells*. Despite being initially intended to provide the digital administration shells for humans specifically, the BASE architecture has been successfully applied to other physical entities – non-human assets/resources and even activities (or processes) (Wasserman, Kruger & Basson, 2023; Defty, 2022). The BASE architecture is visualised in Figure 1.

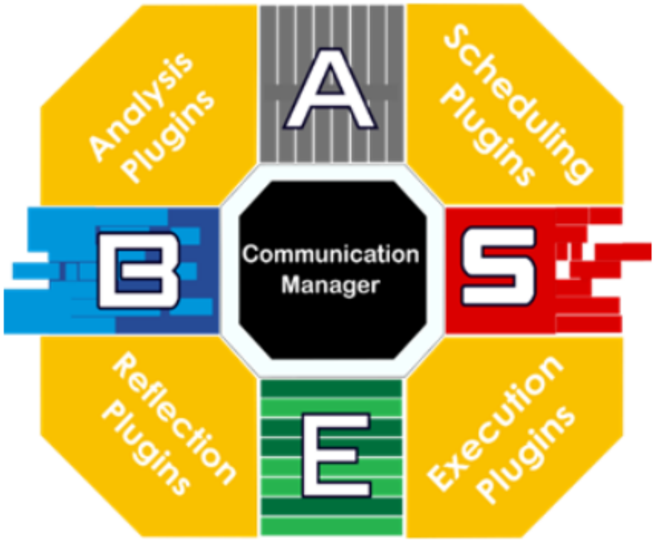

Figure 1. The BASE architecture for digital administration shells (Sparrow, 2021).

The BASE architecture specifies that digital administration shells must consist of both *core* and *plugin* components. The core components are generic and serve as the necessary infrastructure for the administration shell functionality, while the plugin components are interchangeable components, developed to provide the functionality required for a specific application.

The core components of the BASE architecture are: *Biography*, *Attributes*, *Schedule* and *Execution*. The Biography stores data of activities that the physical entity was involved with and relevant data from the worker's surrounding environment. Attributes stores data related to the unique properties of the individual physical entity. The Schedule component manages all data related to the activities the physical entity will be involved with in the future. The Execution component manages all data related to the dynamic state of the physical entity as it performs activities.

The BASE architecture also specifies a *Communication Manager* component. The Communication Manager serves as the gateway for communication between the digital administration shell and other digital administration shells or external digital systems.

The plugin components are the interchangeable and application-specific components of the BASE digital administration shell, which are developed for a specific use case. The BASE architecture defines four types of plugins: *Scheduling Plugins*, *Execution Plugins*, *Reflection Plugins* and *Analysis Plugins*. For a specific application:

- Scheduling Plugins (SPs) will be developed to manage the schedule of the physical entity.
- Execution Plugins (EPs) will be developed to support the physical entity in its performance of tasks (e.g. provide instructions) and gather data to represent the physical entity's dynamic state.
- Reflection Plugins (RPs) will be developed to acquire data on the tasks performed by the physical entity retrospectively and store relevant data to the Biography.
- Analysis Plugins (APs) will be developed to analyse data in the Biography to update the physical entity's Attributes (ensuring an accurate and updated model of the physical entity) and provide insight for decision making.

AN INTEGRATION PLATFORM USING THE BASE ARCHITECTURE

This section describes the development of the integration platform. The design of the platform, as based on the Holonic Systems approach, is discussed first. Therafter, the implementation of the platform using the BASE architecture is described.

Platform design

The integration platform is developed using a *Holonic Systems* approach and the *Biography-Attributes-Schedule-Execution* (BASE) architecture, which allows physical entities in the mine context (human and non-human) to be represented by active, individualised *digital administration shells*.

The Holonic Systems approach employs the philosophy that complex systems can be constructed from an organisation of simpler components – called *holons* – which exhibit the key characteristics of *autonomy* and *cooperability* (Koestler, 1967). Autonomy refers to the ability of holons to encapsulate their own decision-making logic and to perform their own functions. Cooperability refers to the ability of holons to interact with other holons to achieve their own goals/functions, or to collaborate to achieve goals of greater scope or complexity.

The Holonic Systems approach has been applied to the domain of manufacturing systems – resulting in the Holonic Manufacturing Systems paradigm – to support the integration and coordination of complex and dynamic manufacturing processes and resources (Leitão & Restivo, 2006). The approach has also shown promise for application in different domains, such as logistics (Ounnar & Pujo, 2016) and healthcare (Defty, 2022).

To support the Holonic Systems approach to developing the integration platform for mining assets and operations, the Activity-Resource-Type-Instance (ARTI) holonic reference architecture (Valckenaers and Van Brussel, 2015) was used. The ARTI architecture guides the representation of the physical context (in this case, the mine environment) in terms of two types of holons: Resource holons, which represent the resources or assets in the context that can perform services (i.e. tasks or actions that may be useful to the system's operation); and Activity holons, which represent the processes that aim to coordinate the Resource holons to achieve the system's goals.

The vehicles, sensors, utilities (e.g. ventilation system), equipment, mine workers, etc. in the mining context are represented as Resource holons. The processes that coordinate and utilise these resources – e.g. an underground blasting activity – are represented as Activity holons. A depiction of how the various holons can interact, and their resulting organisation, is shown in Figure 2. The implementation of the various Resource and Activity holons and their interactions, by means of the BASE architecture, forms the basis of the integration platform.

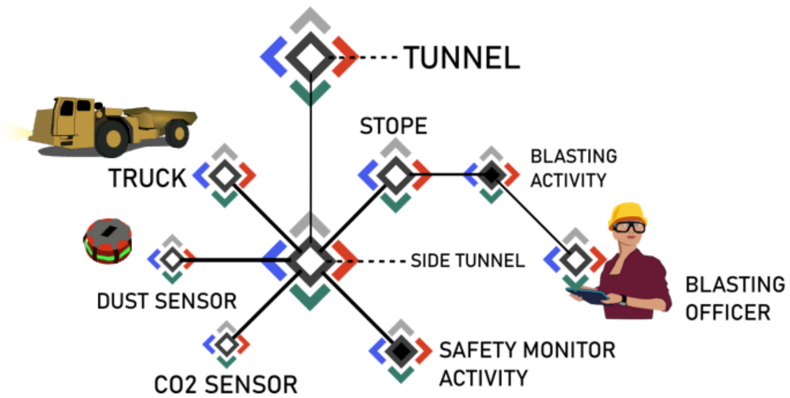

Figure 2. Interaction of Resource and Activity digital administration shells within the integration platform.

Platform implementation

The output of the Holonic Systems approach is the set of holons and their interactions that must be implemented. For the integration platform, each of the holons are implemented by means of their corresponding digital administration shells using the BASE architecture.

The functionality to enable the autonomy and cooperability of each of the holons is implemented through application-specific plugins to the BASE digital administration shells. As such, the digital administration shell of each Resource and Activity holon represented in the platform is equipped with SPs and EPs that allow them to communicate, schedule and execute their own operations. Each holon is also equipped with RPs and APs, which allow the holons to integrate their data and perform analyses on their data, respectively. Furthermore, where digital administration shells must exchange data with physical sources (e.g. capture measurements from sensors or display information to interface devices), EPs were deployed to handle such interfaces specifically.

The digital administration shells of the BASE architecture, and thus the presented integration platform, were developed using the Erlang programming language. Erlang was developed in the telecommunications sector; therefore, this functional programming language is ideal for developing robust, scalable and massively concurrent software systems. Each digital administration shell is implemented as a group of interacting, concurrent software processes.

CASE STUDY

To illustrate the functionality and capabilities of the integration platform, a case study was performed in a simulated mine environment. The case study focussed on the integrated monitoring and coordination of all mining resources involved in an underground blasting activity. The case study was performed in the Smart Integrated Mining Laboratory (SIMLAB) at the Department of Mechanical and Mechatronic Engineering at Stellenbosch University.

Case Study Description

As context, the case study considers a representative section of the underground mine environment – a section of a mine tunnel with branching stope tunnels leading to stope faces, as depicted in Figure 3. The mine environment is equipped with typical sensors and connectivity infrastructure, as illustrated in Figure 4. The mine tunnel provides connectivity to devices via RS485, Ethernet and WiFi, which connect to the mine's main underground fibre network. The stope tunnels provide connectivity through a Bluetooth low-energy network. Furthermore, the case study context includes computation devices in the mine tunnel, as well as at the entrances to each of the stope tunnels.

For the case study, the integration platform will ingest, process and contextualise the data from the stope and mine tunnel sensors to:

- monitor and coordinate the human and non-human resources involved in an underground blasting operation; and
- provide real-time, human-centred and contextualised information on underground operations to the aboveground control room and a Cloud-based Geographical Information System dashboard.

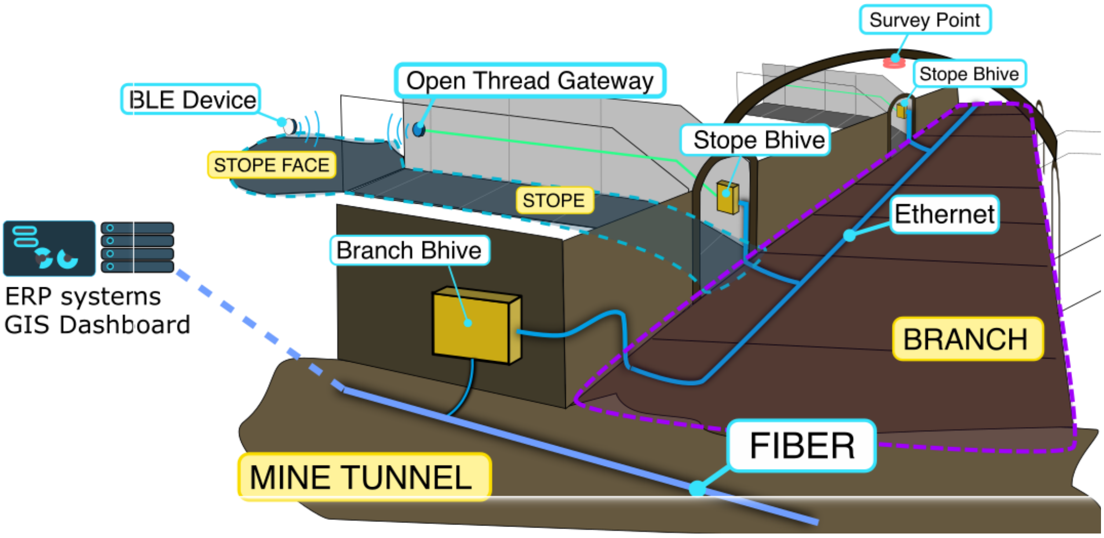

Figure 3. Case study underground mine environment.

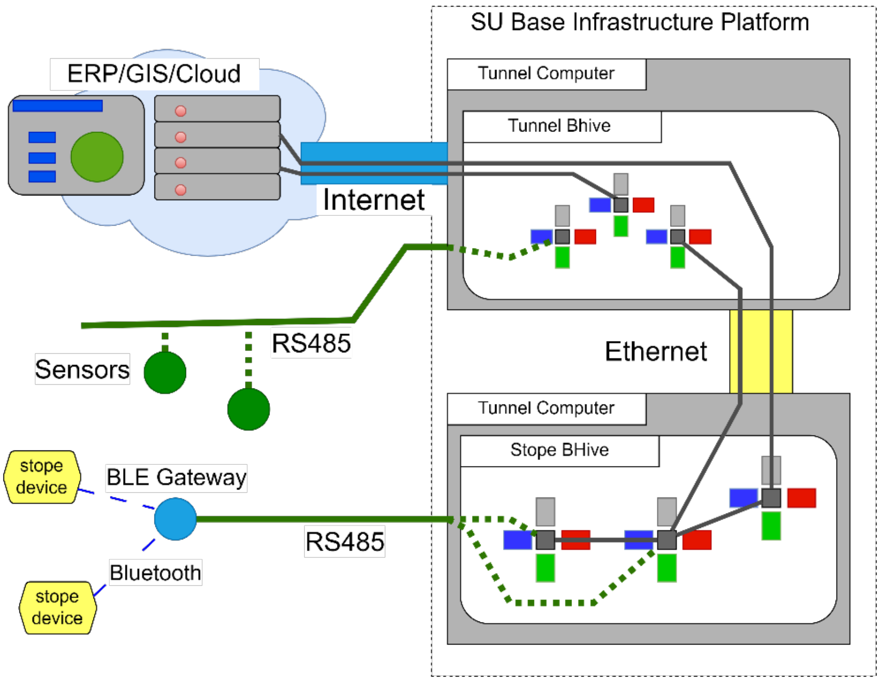

Figure 4. Data flows from stope devices to the integration platform and through to the Cloud dashboard.

Test Scenario

The SIMLAB is an aboveground testbed for researching and evaluating digital underground mining technologies – specifically focussed on the integration of such technologies and the coordination and monitoring of underground resources and operations. Figure 5 shows the SIMLAB configuration to represent a test scenario that matches the case study. The SIMLAB is equipped with the connectivity infrastructure (as per Figure 4) and sensors (for measuring atmospheric conditions and for proximity detection) within the replicated mine and stope tunnels.

Figure 5. SIMLAB mine and stope tunnels.

Integrated Monitoring and Coordination
For the case study, a blasting activity was selected as a typical mining business process that involves the coordination of multiple human and non-human resources. Blasting activities also emphasise the importance of traceability of underground operations. The integration platform must thus perform functions related to near real-time monitoring and coordination, while acquiring, intergating and contextualising relevant data for various sources to enable traceability.

For the case study, the integration platform deployed BASE digital administration shells for all the human and non-human resources involved in the blasting activity, as well as a digital administration shell that represents the blasting activity itself – corresponding to the architecture shown in Figure 2.

The digital administration shells developed and deployed for non-human resources included those for the various sensors (such as the dust monitor and gas level sensors), proximity detection system, ventilation system, and simulated vehicles and equipment. The mine tunnel, as an integration point for all the operations and data in the underground environment, was also represented by a digital administration shell. Digital administration shells were also deployed for each of the interface devices (specifically, the blasting officer's hand-held device and the control room dashboard).

A digital administration shell was also developed and deployed for each mineworker. For each mineworker, their digital administration shell continuously (and in near real-time) integrated data related to their exposure (from the digital administration shells representing the tunnel sensors) and location (from the digital administration shell representing the proximity detection system). The digital administration shell for the blasting officer also integrated exposure information and was further equipped with plugins that gather data from other resources regarding the execution and progress of the blasting activity.

The digital administration shell that represents the blasting activity implemented plugins that coordinate the sequence of operations required for a successful blasting activity. This shell gathers data from the resources represented within the integration platform in order to monitor the progress of the activity, and communicates instructions to the relevant resources.

The digital administration shells of the mine tunnel, mineworkers and blasting activity provided contextualised information to the data interfaces of the integration platform. Each of these interfaces were maintained and managed by a dedicated digital administration shell as well – equipped with the functionality to process and display integrated information and to capture and communicate decision-maker input. An example of the control room interface is shown in Figure 6.

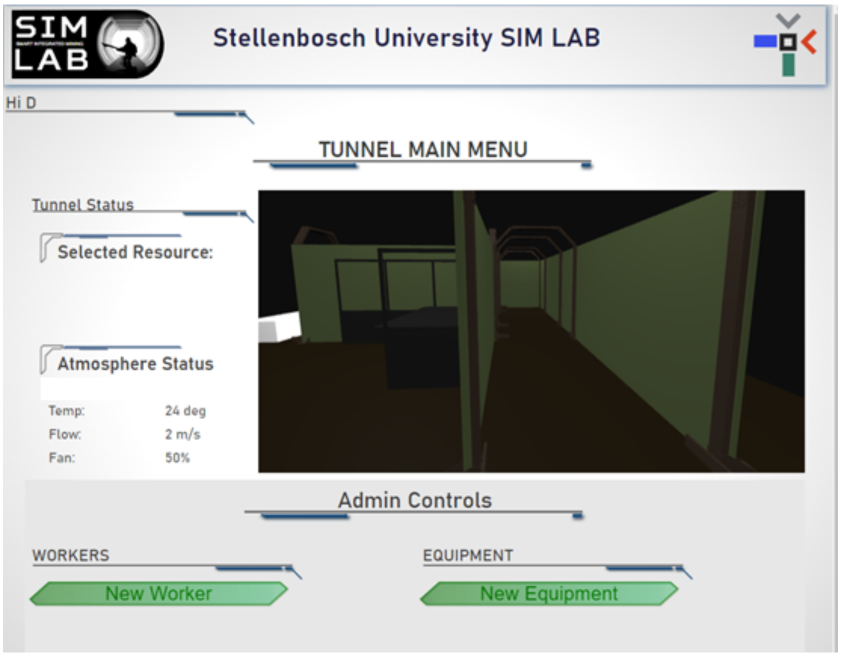

Figure 6. Example output of the control room interface.

CONCLUSION

The paper presents an integration platform for smart, integrated mining. The platform aims to address the challenges of functional and data integration of systems, human and non-human resources and operations involved in the underground mining operations.

The development of the integration platform is described, with the platform design guided by the Holonic Systems approach and the implementation thereof enabled by the BASE architecture for digital administration shells. As a result, the integration platform is composed of various autonomous and cooperative entities that actively represent the physical resources and processes present in the underground mining operations.

The functionality of the integration platform was discussed by means of a case study. The case study considered a typical underground mine environment (replicated in the SIMLAB testing facility) and a representative mining business process (an underground blasting activity). By means of the case study, the functionality and role of the various digital administration shells executing within the integration platform was discussed.

Future work on the integration of underground mining resources and processes will focus on deploying and evaluating the integration platform in real underground environments. Challenges to be addressed include: achieving interoperability between a diverse range of systems, technology and suppliers in the mining sector; achieving software system reliability that is similar or better than existing systems; and achieving technology acceptance by mines and mineworkers. The last challenge will be addressed in planned future work to expand the functionality of the mineworker BASE digital administration shell and related technologies.

ACKNOWLEDGEMENT

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Dr Dale Sparrow completed his PhD in mechatronic engineering at Stellenbosch University in 2021. His PhD developed a digital platform for human and system integration in Industry 4.0 environments. He has since guided the commercialization of the platform as CEO of the technology start-up company, Cybarete.

Integrated execution and materials management

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Integrated Execution and Materials Management (IEMM) is a holistic approach to streamline and optimize supply chain operations, combining real-time data-driven decision-making from the execution environment with efficient materials management. Every year mining organizations write off materials due to damage, loss, or expiry. This paper aims to address ways to reduce the risk in under- or over-stocking of critical items and get close to just-in-time materials ordering. By leveraging advanced technologies such as interoperability, data analytics, and execution systems, IEMM provides visibility and control over the entire supply chain by linking directly to execution and planning systems. Adopting IEMM empowers organizations to stay competitive in a dynamic business environment, ensuring the right materials are available at the right time and place, leading to better resource allocation and overall operational excellence.

INTRODUCTION

This paper aims to discuss the integration of materials management with short interval control to unlock value in supply chain operations. The topics covered include an introduction to the concept, the potential value to be unlocked, the importance of system integration, the role of short interval control and a conclusion summarizing the benefits of this approach.

In the Deloitte State of Mining Trends 2023 [3], key themes emerged related to technology advances. This includes items like building resilient supply chains and using system thinking to drive next-level operational excellence. This paper aims to highlight what is possible by linking materials and supply chain management to operational planning.

Planning within mining companies has evolved a great deal in the last few decades with the start of the 4th Industrial Revolution. This means greater access to information and more systems available to solve operation problems. Unfortunately, the increase in tools available to mining companies highlighted a greater need for inter system communication. On any mining site you will find a combination of planning-, modelling-, equipment tracking-, material tracking-, and supply chain systems. These systems are supported by various applications including Excel and various dashboard functionalities.

Enterprise resource systems added to the complexity and Gartner [4] reveals that over 40% of services companies will unify core processes like financials, human resources, procurement, and operations into a single suite by 2026. Enterprise systems were historically disconnected from the planning and scheduling environment. The planning and scheduling environment is managed by mine planning and operational teams, and ordering and planning of materials is decoupled from this process. This will generate vast amounts of data.

Mining companies aim to reduce the stock at hand to lower risk of damaged spares as well as items going to waste due to not being used. Often this stock on hand can be represented as a percentage of stock required at any given time over a monthly period. There is a fine balance between stock at hand to keep the operation running smoothly and having too much.

By employing a system thinking approach to execution and resource planning along with various interoperability platforms available, these systems can now be connected into a single source that is readily available to various mining departments, without the requirement for manual file and data transfers. This approach will be able to quantify the short medium- and short-term stock requirements.

Mine technical systems have been changing the way data is accessed and distributed within an operation. Where once systems were seen as a standalone system, interoperability concepts have allowed systems to start sharing data between platforms on a system-to-system basis or system to central network basis. This has allowed solutions to be built that expand on the capability of a single system and start to leverage information from multiple systems into a single holistic solution. This materials management paper aims to provide not just a single solution but aims to highlight what is possible with system integration.

This paper will not only focus on technology and processes but also touch on the role the human plays in the successful adoption of information systems.

INTEROPERABILITY CONCEPT

Interoperability is a new concept and means "the ability of computer systems or software to exchange and make use of information". It also means the ability of military equipment or groups to operate in conjunction with each other but that is for another day. In its simplest form it means data from different vendors can be combined into a single source by means of connection over a wide area network or local area networks.

Interoperability is because of the Fourth Industrial Revolution where connected system and the Internet of Things came to the fore. A means to connect disparate applications together to solve a single problem was required. The Drawing Exchange Format or DXF file as known in the computer-aided drafting was the first truly interoperability standard that allowed mining software packages to make data available between systems. However, this format was a static file-based solution. To share information, it had to be manually created, exported, saved to a location, and then manually imported on the other side. Meaning that if any changes were made to the original data, the previous file would be out of date.

Questions arise about the current physical state of an operation, wondering if it's as up to date as when the original creator of the data was involved. Without a robust naming convention, this understanding becomes even more challenging; there could be a mismatch of up-to-date information. Interoperability solved this problem by moving away from static file-based concepts and into a live single feed or stream of data to a single platform from where data can be accessed and utilized.

Moving from syntactic to semantic interoperability[2]

As soon as systems started communicating with other systems, the language used started changing as well. What start as a file-based communication system, evolved into models that both the sender and receiver could read without translation. This is where the terms syntactic and semantic communication models started being addressed.

Syntactic interoperability means the standardization of the communication between a software client and a server, but some form of decoding still has to occur on the receiving side. Examples of syntactic communication are Extensible Markup Language (XML) and Structured Query Language (SQL) formats. The example below shows the Open Geospatial Consortium (OGC) data format for spatial data that requires conversion to interpret data to a usable format on the receiving end.

WKB Data Type (OGC Compliant)
0x01082B000004000000010000000000001016C0D6400000C0CB531B24410000000038B411C00100001CE5
BFD64000004021571B24410000000038B411C0000000E80EC0D6400000A059551B24410000000038B411C0
000000E80EC0D6400000A059551B24410000000038B411C000000000010000000200000C5100000

Semantic[1] interoperability is the ability to automatically interpret the information exchanged meaningfully and accurately to produce useful results as defined by the end users of both systems. Semantic interoperability refers to not having to decode data from one system to the next. It uses the same data model at the origin as the destination. A semantic data model aims to add value to the data and present the data in a logical way. This can be seen as data that can relate to other data. This can also be seen as relational data. The use of semantic or syntactic data depends on the systems and data to be shared.

Example of data models
Data models represent an enterprise's data to be shared between systems and functions. The data model helps to identify the underlying structure in the context of the relevant business process. Mining companies are starting to build on the several ways data can be shared between systems, each with advantages and disadvantages. Depending on the data requirement, each model will provide advantages and disadvantages. There are many data models available within the engineering and financials sectors, but this paper will focus on a few main models being employed currently within mining companies. Figure 1 indicates the most basic structure, where files are shared between systems by exporting from one system and then imported into a second system. An example of this data is where a DXF file is exported from one mining software package and imported into another software package.

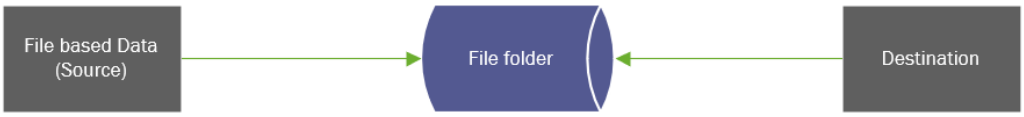

Figure 1. File-based data.

Another way of sharing data between systems is by using SQL to share data between systems. This requires both systems' data to either be available in a database management system or be converted into SQL language data. The process of converting data from file-based systems to SQL data can be automated. Systems will generate live views with the SQL environment and the ability to read will result in only current data being used, meaning that there is only one version of the truth and not multiple, static datasets. The process of extract-transfer-load (ETL) can translate data into a meaningful data model that can be translated by the receiver and destination. Figure 2 below highlights what a SQL data connection could look like as well as the process to convert data to a SQL format. The system below can also be seen as an application-to-application model where data is shared between two systems using similar data.

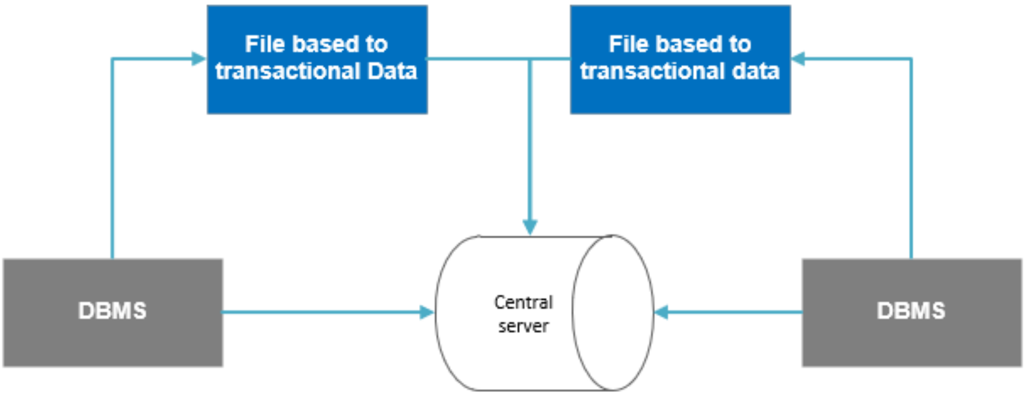

Figure 2. SQL to SQL data model.

A more complex model is where data from various sources are required to solve a cross-functional problem. An example could be where materials data from an enterprise system is required to interact with mine planning or execution data to provide a live data view for materials. For this model various applications or functions require data for varied reasons. There is no one-to-one relationship between systems. The model employed is called a data lake model. A data lake is a central data repository designed to store structured, semi-structured or unstructured data. Semantic or syntactic formats could be utilized within the data lake and each application will decode the data required. Figure 3 below shows where operational planning data, enterprise data for materials, equipment sensor data and application data are combined to be used in a central reporting platform. Each data provider will provide data in a native format and applications will ETL to ensure the data is in a usable and logical format.

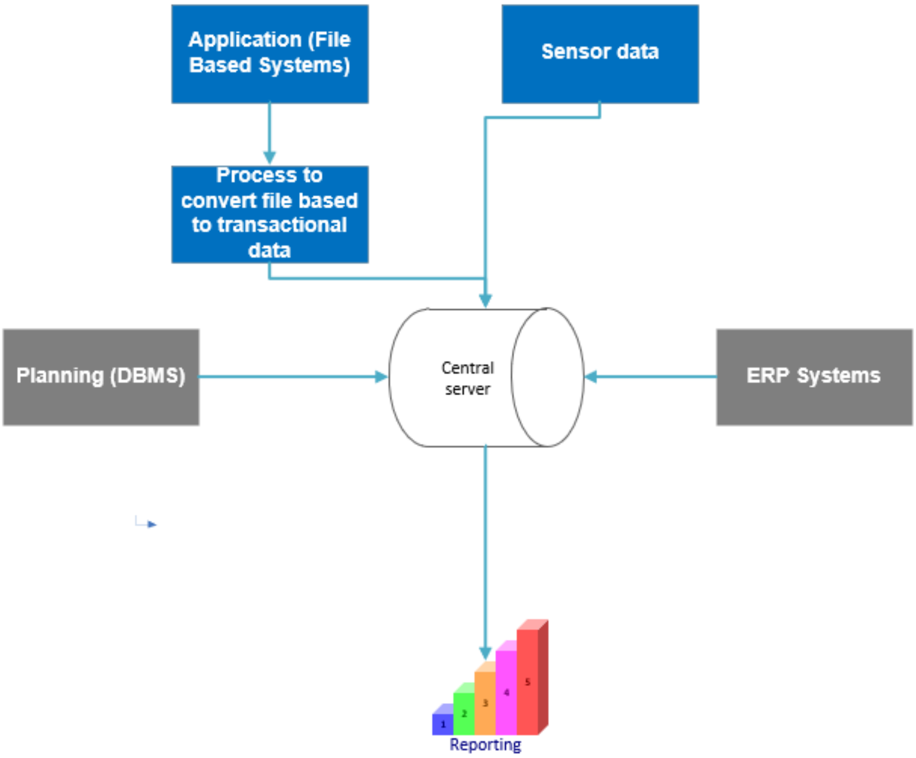

Figure 3. Data lake model.

Many different data models exist, and mining companies will continue to expand knowledge and use of the various systems. Companies like Amazon Web Services or Microsoft Azure provide data lake options for a cloud-based solution. The following is a brief list of data models in use today:

Hierarchical Data Model
This model represents data in a tree-like structure, with one root element and multiple levels of child elements branching out. Each child element has only one parent, while a parent element can have multiple children. This model is commonly used in file systems and XML documents.

Network Data Model
The network model is an extension of the hierarchical model, allowing child elements to have multiple parent elements. It forms a complex network of interconnected records, enabling more flexible relationships between data entities.

Relational Data Model
This model represents data as tables (or relations), where each row (or tuple) contains a unique record, and each column represents an attribute. Relationships between tables are established using primary and foreign keys. The relational model is the foundation of most modern relational database management systems like MySQL, Oracle, and PostgreSQL.

Entity-Relationship Model
The Entity-Relationship (ER) model is a high-level data model that helps in designing databases using entities (objects), attributes (properties), and relationships (associations). Entities are represented by rectangles, attributes by ellipses, and relationships by diamonds in an ER diagram.

Object-Oriented Data Model
In this model, data is represented as objects with attributes and methods (functions). Objects can inherit properties and behavior from other objects, enabling code reusability and modular design. This model is commonly used in object-oriented programming languages like Java, C++, and Python.

NoSQL Data Models
NoSQL databases use various data models to manage unstructured, semi-structured, or distributed data. Common NoSQL data models include:

- Key-value stores: These are the simplest type of NoSQL databases. Every single item in the database is stored as an attribute name (or 'key'), together with its value. Examples of key-value stores are Redis, Voldemort, and Dynamo.
- Document databases: In these databases, data is stored in documents, which are grouped together in collections. Each document can have an entirely different structure. MongoDB and CouchDB are examples of document databases.
- Wide-column stores: These store data as columns instead of rows and can quickly aggregate enormous amounts of data. They are excellent for analytics. Examples include Cassandra and HBase.
- Graph databases: These are used to store information about networks, such as social connections. Graph databases include Neo4J and Giraph.
- Time-series databases: These are optimized for handling time-series data, i.e., data that's indexed by time (a datetime or a datetime range). Examples: InfluxDB, OpenTSDB.
- Search engines: They provide more complex query capabilities and are optimized for searching text, often across large amounts of data. Examples include Elasticsearch and Solr.

EXECUTION OF THE PLAN

Mine planning can be broken into four distinct planning horizons, namely: strategic, tactical, operational and contingency. Contingency planning includes more detailed action items related to changes in specific conditions or unexpected events and will be excluded from this paper. The primary focus of this paper is to highlight how material management can be improved within the operational planning phase. The operational planning phase relates to the day-to-day issues such as resource assignment. This planning horizon will have detailed objectives with concrete deadlines and task assignments.

The term 'task assignment' will be a key term in linking materials to a specific task. In a project, on which this paper is based, materials are linked to specific tasks that needed to be performed. This can also be called short interval control. According to the Global Mining Guidelines Group[5] short interval control is "a structured process for identifying and acting on opportunities to improve effectiveness and efficiency of mining processes (production, development, and services). The intended outcome is a continuous improvement loop of improving productivity and wasting less time."

Establishing an accurate task structure
Short interval control relies on increased accuracy for day-to-day planning. This includes drilling down tasks into subsequent work packages. Work packages are a mining activity broken down into smaller activities. Mining an end could be broken into drilling, blasting, loading. These activities are work packages. A mining task from a planning perspective as an example will be capital development. This capital development activity will then be broken up into smaller work packages. For this capital development to be completed the following items will be added as sub-tasks:

- Primary Support - development
- Development marking
- Development drilling
- Drill suspension holes

- Development charging
- Development blasting
- Development loading
- Development trucking
- Development scaling
- Development loading - scaling
- Development trucking – scaling

The above is an example of a work package. When completed, the entire operational work package could end up looking like the representation in Figure 2 – which shows how main activities are broken down into sub-activities for accurate work prediction.

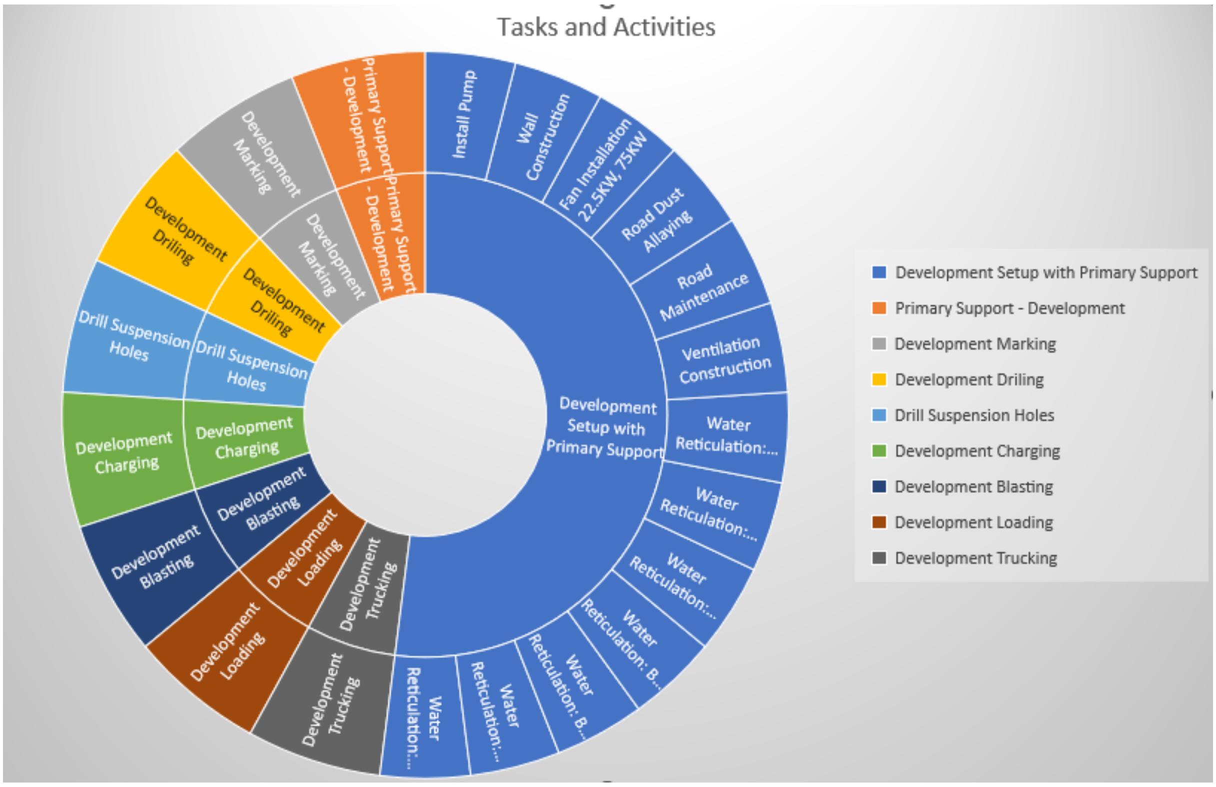

Figure 1. Sunburst representation of tasks and sub-tasks.

The demonstration of this proof of concept included 29 main tasks and a total of 252 sub-activities. Each activity then had materials assigned in the construction of a Bill of Materials. Table 2 indicates a standard bill of materials (BOM) design. The BOM is constructed for all materials required to be included in daily monitoring.

The source of short-term planning schedules can vary within operations, but the information contained within remains consistent. The schedule will contain fields including the following: task name, workplace, start time, resource, quantity, duration, predecessors and successors. The source could be anything from Excel to specific short interval applications. Interoperability tools will allow this schedule to be made available within a database environment, from where the link to the material and bill of quantities (BOQ) will be established.

Both the BOM and the BOQ are important documents that are used in project planning and management, but they serve different purposes and are used in different industries.

- BOM: This is a list of raw materials, parts, components, and the quantity of each needed to manufacture an end product. It's often used in the manufacturing industry. A BOM is more than just a shopping list; it provides the manufacturer with a detailed roadmap on how to build the product and also helps in inventory control, maintaining records, and purchase planning.
- BOQ: This is a document used in the construction industry that provides project-specific measured quantities of the items of work identified by the drawings and specifications in the tender documentation. It is typically prepared by a quantity surveyor or a cost engineer. The BOQ assists tenderers in the calculation of construction costs for their tender and is also used as a baseline to assess changes to the scope during the construction phase.

Establishing a material consumption baseline
For effective material management and the tracking thereof, a baseline for the materials linked to tasks needs to be created. An example would be that for a 3 m blast an advance team will require 10 square meters of mesh. In underground operations such as mining, a mesh is commonly used for safety purposes. This safety measure, often referred to as 'rockfall mesh' or 'rock mesh', is designed to prevent rocks and other debris from falling and potentially causing harm to workers or equipment. By looking at historical usage patterns, if available, a BOM can be constructed with a certain degree of accuracy and then improved on in subsequent months. This is an iterative process.

Table I. Creation of a bill of materials example

Task Name	Material Code (ERP)	*Description*	*Quantity*
Development Drilling	1000220	Roof Bolts	13
Development Charging	1023200	4.5m 2500MS Delay	6
Development Charging	1023201	4.5m 500MS Delay	6

BOM configuration is a critical component of the Integrated Materials Management (IMM) approach. By monitoring material flows and key performance indicators at regular, short intervals (e.g., hourly or daily), organizations can:

- Quickly identify deviations from planned material usage and procurement.
- Address operational issues or inefficiencies in near real-time.
- Make data-driven decisions to optimize material usage, minimize waste and reduce costs.

The BOM configuration can be done through a dedicated materials management enterprise resource planning ERP application or could be done within a database structure. It is essential to understand who the owner of the BOM will be and where the iterations of adjusting the bill of material structure will take place. During a proof of concept of this, the following information became clear. ERP is a type of software that organizations use to manage day-to-day business activities such as accounting, procurement, project management, risk management and compliance, and supply chain operations. The ERP system integrates these various functions into one complete system to streamline processes and information across the entire organization.

Table II. Prediction mode updates

Month	Materials Predicted	*Materials Used*	*Accuracy*
Month 1	2515	3170	126%
Month 2	3315	3520	106%
Month 3	3211	3420	107%

Table II above shows that iterations of the model and review each month of average material usage will slowly start closing the gap between prediction and actual usage. The proof of concept above focused on only 36 different consumables including explosives, explosives consumables like timing accessories, mesh, ventilation equipment, electrical cable and a few more.

The materials adjustment and reconciliation rely on two key elements: 1: The quality of the plan for the duration ahead and 2: The quality of the material prediction model. Both these elements will play a critical role in ensuring the predicted usage accuracy. Iterations and reviews conducted at the end of each month enable the refinement of this model, specifically tailored to the materials required for a given month. Once the materials needed on a daily, weekly, and monthly basis have been finely tuned, this model can then be applied to a yearly budget. The accuracy and the time needed to construct this budget will consequently improve.

The biggest advantage that a materials management system will drive is removing the reliance on human input for the prediction and start moving to a prediction model, as driven by actual mine planning parameters.

LINK TO ENTERPRISE RESOURCE PLANNING SYSTEMS

ERP software is a critical component of an IMM system. IMM involves managing the entire supply chain of an organization, from raw materials to finished goods. ERP software provides a central platform for managing all aspects of the supply chain, including inventory, production, sales, and logistics. It helps to ensure that all departments have access to the same information in real-time, enabling efficient decision-making and reducing the risk of errors. ERP also plays a crucial role in automating key processes, such as purchase order creation and inventory management, which can improve accuracy and reduce costs.

ERP systems responsible for supply chain management are mostly database-based systems. Systems like SAP and Dynamics 365 use databases to store information. SAP uses its proprietary database system called SAP HANA, while D365 uses Microsoft SQL Server. The DBMS is responsible for storing, managing, and retrieving data used by these systems.

As ERP systems are already database-enabled, the BOM and execution schedules can be brought together in a single database platform through interoperability processes to complete the communication chain.

From there the information can be combined into a single dataset that can be utilized to both view the estimated model, but also track against the actuals. The report can be constructed on a reporting platform like Power-BI and up to date reports available at all times. Table III below is an example of such a report. This automated reporting platform will replace the reliance on static data sources like Excel and will always be up-to-date based on the planning information provided.

Table III. Bill of quantities for each activity

Name	TaskType	MaterialName	Price(R)	Numberof	Cost
DDEC001	Development Charging	INNOFEX, 25KG MULTIBAG	350	15	5250
Drill_Drive 335	Development Charging	INNOFEX, 25KG MULTIBAG	350	12	4200
Drill Drive 315	Development Charging	INNOFEX, 25KG MULTIBAG	350	12	4200
E_XC335	Development Charging	INNOFEX, 25KG MULTIBAG	350	15	5250
E_XC315	Development Charging	INNOFEX, 25KG MULTIBAG	350	15	5250

CONCLUSIONS

IMM is an essential strategy for companies aiming to strengthen their value proposition through streamlining supply chain operations. This method amalgamates key functions like procurement, inventory management, logistics, and production planning into a unified system, thereby enhancing material flow within the organization.

Effective deployment of this strategy necessitates a culture shift towards cross-functional collaboration within the organization, coupled with strategic investments in technology infrastructure and software platforms like SAP and Dynamics 365. These systems, crucial for successful materials management, provide the ability to accurately monitor inventory levels, track material flows, and plan production schedules.

Value creation stands at the core of IMM. The strategy facilitates this by increasing efficiency, heightening customer satisfaction, and cutting costs. By consolidating various functions within an organization, businesses can reduce duplication of efforts, enhance material flows, and decrease the time and expense related to the production process. Superior inventory management and procurement practices also contribute to reducing inventory levels, minimizing waste and improving working capital.

In essence, IMM is a key strategy for organizations striving to optimize their supply chain operations, boost their value proposition, and maintain a competitive edge. It demands an organizational cultural shift, technology infrastructure investment, and cooperative approach. By unifying contrasting functions, businesses can improve efficiency, lower costs, and optimize material flow, ultimately adding value for their customers and stakeholders. Therefore, embracing IMM is crucial for any company aspiring to stay competitive in today's fast-paced business landscape.

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