Proceedings of the 8th European Conference on Industrial Engineering and Operations Management
Paris, France, July 2-4, 2025

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/EU08.20250165
Published: July 2, 2025

Drivers and Barriers to Digital Technology Adoption in South African Mining: A Qualitative Study

Leago Sathekge
Department of Engineering and Technology Management, Faculty of Engineering and the Built Environment, University of Pretoria, Pretoria, South Africa
sathekge.tl@gmail.com

Hannelie Nel
Associate Professor in Engineering Management
Department of Engineering and Technology Management, Faculty of Engineering and the Built Environment, University of Pretoria, Pretoria, South Africa
hannelie.nel@up.ac.za

Marthinus du Plessis
Researcher and Innovation Consultant
Department of Engineering and Technology Management, Faculty of Engineering and the Built Environment, University of Pretoria, Pretoria, South Africa
marinus.6108@gmail.com

Abstract

Technological transformation is a key enabler for the future of mining. For a mining future to be possible, it will require that mining and metal companies change their mindset and business models as sustainability becomes imperative. Although all forms of innovation are important, digital technologies are more likely to have a greater impact on multiple productivity factors because they can transform the mine business model from start to end. The combined effects of several digital technologies bring about digital transformation. Digital transformation is said to be an unavoidable trend that can enable new value-creation mechanisms among organisations. There is a deficit of transformational innovation in the mining sector as compared to other sectors. And as the cost of extracting minerals continues to rise, along with other challenges, digital transformation presents a strategic opportunity that enables value creation opportunities. This research explores the intention of mining organizations in South Africa (SA) to adopt digital technology. A qualitative study was employed to ascertain the level of adoption of digital technology across mines in SA and determine the drivers that influence the adoption of digital technology, as well as the barriers that impede its adoption.

Keywords
Digital technology, digital transformation and mining.

1. Introduction
The mineral resources (MR) industry is an integral part of any conceivable economy and society. As a provider of employment and essential materials, it is connected to almost all industries' value chains. Globally, mining operations are approximately 28% less productive today than a decade ago. This indicates a decline of 3.5% per year (Lala et al.

2015). The stakeholder landscape for mining and metals companies is also becoming increasingly challenging, with growing expectations for companies in this field to operate in a responsible and sustainable manner.
Mining companies in the South African landscape also face tough mining conditions as ore grades at current depths have declined, and companies need to mine at increasing depths to reach new economically viable deposits. Since the year 2000, 75% of new base metal discoveries have been at depths below 300m. Gold mining in SA has declined from over 1000 tonnes in the late 1900s to a mere 133 tonnes in 2014, with many mines closing due to escalating costs at depth. The industry is also extremely vulnerable to any hostile movements of variables such as global demand for commodities, low commodity prices, rising exchange rates, and all other administered price increases. Nearly "50 % of the intermediary input costs are influenced by administered prices" (Mineral Council South Africa 2019). However, the South African minerals resources industry still contributes significantly to the gross domestic product (GDP) of SA, with an 8.1% direct contribution to the 2019 GDP. The MR industry is also one of the largest employers in the country; thus, a sustainable approach is required to address the current challenges faced by South African mines. Bryant (2015) argues that technology is a key foundation and an enabler for a mining future. The mining industry is ready for technological transformation and advancement after such a lengthy period of relative stagnation in technological advancement.

This research has three objectives: (1) to explore the level of preparedness to adopt digital technology across mines in South Africa, (2) to determine the drivers that influence the adoption, and (3) to determine the barriers that impede the adoption of digital technology in a South African context.

2. Literature Review

Digital technology is defined as, "electronic tools, systems, devices and resources that generate, store or process data" (Dibaba and Babu 2017). The adoption of these technologies is said to enable more efficient collaboration among ecosystem partners (Gao et al. 2019). Muller et al. (2018) refer to this connectedness as "Industry 4.0". This concept "is based on an advanced digitisation of production processes and the combination of internet-oriented technologies, allowing the connection between smart sensors, machines, and IT systems across the value chain," (Sanchez and Hartlieb 2020). Digitisation and interconnection of industrial processes intended by Industry 4.0 are facilitated by data analytics, machine learning, and artificial intelligence (Müller et al. 2018). Sganzerla et al. (2015) draw a direct relation between digital and the novel ways information is produced and utilised. The amount of information available is increased by the Internet of Things, while distribution and utilisation of the information will be made possible by mobility.

Digital transformation (DT) is the integrated, widespread organisational adoption of digital technologies to enable major business improvements (Fitzgerald et al. 2013). Digital transformation creates change across all departments, whereas isolated changes are digitalisation efforts. Gao et al. (2019) define digital transformation as a "technology-enabled strategic change". "Digital transformation is the process by which entities adapt themselves to modern technology" (Young and Rogers 2019; Sanchez and Hartlieb 2020). According to van Dyk and van Belle (2019), digital transformation alludes to an enterprise business model that applies novel or current digital technologies, services, or products into digital variants to offer substantial products to their clients. Although there has been growing interest in the use of digital technologies in the MR industry worldwide, attempts at digital transformation are lagging behind other industry sectors (Gao et al. 2019). "Despite large strides towards DT by other industries, many mining companies are struggling to even begin" (Young and Rogers 2019).

2.1 Digital Maturity

The rise of digital technologies has become a significant influence on change in many industries (Salviotti et al. 2019; Rossman 2018), and this trend necessitated alterations in existing business model frameworks (Fitzgerald et al. 2013). As such, "organisations must assess their current business model against emerging opportunities and potentially adapt it to the new digital era" (Gannon 2013). In response to this phenomenon, modern literature has created the concept of digital maturity (Remane et al. 2017). Digital maturity is defined as an organisation's development of digital capabilities to manage the digital transformation process successfully by using digital tools and strategies (Kane et al. 2017; Bergaus et al. 2017 cited in (North et al. 2019). A maturity model offers direction on how companies approach their transformation and outlines ways of how companies undergo transformation (Rossmann 2018). These models assist organisations in assessing their ability to undertake digital transformation per pre-defined dimensions. Especially in the case of transformation journeys, they can help in understanding the state and the capabilities of an organisation in successfully handling and directing digital transformation efforts in a methodical manner. Digital maturity models are made up of factors and criteria that describe areas of action and measures at varied levels, which denote the progression toward maturity (Berghaus and Back. 2016, cited in Teichert. 2019). The principal idea behind maturity models, whether general or digital, is a set of overlapping investigations into the gap between the company's current and future capabilities.

Rossman (2018) finds that digital maturity contains eight dimensions and 32 accompanying items, including: strategy, leadership, business model, operating model, people, culture, governance, and technology. Aslanova and Kulichkina (2020) support this view by finding that digital maturity is distinguished by five main elements namely, strategy, organisation, people, technology, and data. Rossman (2018), supported by Salviotti et al. (2019), further suggests that there is no constant definition of digital maturity available due to the heterogeneity in content and methodology of the different maturity models. Kane et al. (2017) measure digital maturity by asking respondents to "imagine an ideal organisation transformed by digital technologies and capabilities that improve processes, engage talent across the organisation, and drive new value-generating business models." The respondents are then asked to rate their organisations against that ideal using a scale of 1 – 10. An organisation's digital maturity is classified as either early (1-3), developing (4-7), or maturing (7-10).

2.2 Technology Adoption Theories

Identifying the correct technologies and implementing them successfully to deliver results requires a scientific and structured process. In this study, we evaluate ideas for firm-level adoption models found in the information systems (IS) literature. Adoption models used in IS literature are the most prevalent and widely developed. The three theories addressed are Rogers's (1995) diffusion of innovation theory, Tornatzky and Fleischers (1990)'s Technology, Organisation, and Environment (TOE) framework, and Iacovou et al (1995).

The diffusion of innovation (DOI) hypothesis describes how, why, and at what pace new innovations and technologies move across cultures, impacting both people and companies. Innovations spread via certain means throughout time and within a particular social structure (Rogers, 1995). According to Rogers's (1995) DOI theory at the company level, innovativeness is linked to independent factors such as human (leader) qualities, internal organisational structural features, and external organisational characteristics such as (a) Personal qualities indicate the leader's disposition toward change. (b) Internal characteristics of organisational structure include the following: "centralisation is the degree to which power and control in a system are concentrated in the hands of a relatively few individuals"; "complexity is the degree to which an organisation's members possess a relatively high level of knowledge and expertise"; and "formalization is the degree to which an organisation's members possess a relatively high level of knowledge and expertise." (c) The term "external characteristics of an organisation" refers to the openness of the system. In 1990, Tornatzky and Fleischer, developed the technology-organisation-environment (TOE) framework. It examines two facets of an enterprise's environment, organisational and external, as well as characteristics of the innovation itself that affect how enterprises accept and execute technological innovations (Tornatzky and Fleischer, 1990).

- The term "technological context" refers to both internal and external technologies that are critical to a business's functioning. This covers both the company's existing procedures and equipment and a collection of publicly accessible technology.
- The term "organisational context" denotes the expressive characteristics of an organisation, including its scope, size, and management structure.
- The environmental context refers to the operational environment in which a business operates—its industry, rivals, and interactions with the government.

The TOE framework, as presented and modified in subsequent IT adoption studies, offers a helpful analytical framework for assessing the acceptance and assimilation of various kinds of information technology innovation. Although the TOE paradigm is theoretically solid, empirically consistent, and relevant to areas of information technology innovation, the factors found in each of the three contexts vary between researchers. The TOE framework comes with a new and critical component dubbed the environment context. Iacovou et al. (1995) examined how the features of inter-organisational systems (IOSs) affect companies' acceptance of information technology advances in the context of technology adoption. The author's approach is excellent for explaining why an IOS is implemented. Three elements contribute to this determination: perceived advantages, organisational preparedness, and external pressure (Iacovou et al., 1995). While perceived benefits are distinct from the TOE framework, organisational preparedness is a composite of the TOE framework's technology and corporate environment. Thus, information technology resources are associated with technical environments, while financial resources are associated with organisational contexts. External pressure is essential for IOS adoption in the Iacovou's et al. (1995) theory because it augments the external task environment of the TOE framework with trade partners.

2.3 Technology Adoption in the Minerals Resources Industry

Technology planning and forecasting, especially in the form of road mapping, is not an existing culture in mining firms. When organisations were inclined to pursue digital transformation, their organisation was not able to support the change. This leaves an impression that the introduction of new technology may be done without developing a culture and operational requirements that can ensure the successful implementation of said technologies (Amadi-Echendu et al. 2011; Gao et al. 2019). When the historical pace of systemic change in an industry is low, firms lose their dynamic capabilities to change. This stresses a more conservative technology planning and forecasting approach by mining firms (Amadi-Echendu et al. 2011; du Plessis and Pretorius 2017). From literature, six elements were identified as having a great influence on how technology is adopted in the MR industry,

- Strategy – Amadi-Echendu et al., (2011) found that mining organisations readily respond to market pull rather than technology push, adopting a reactive approach when it comes to technology application. Innovation effort in the MR industry is focused on the optimisation of existing technologies and are directed at lowering costs (du Plessis and Pretorius 2017). The top drivers being health and safety, environmental regulations, and production targets. Factors like competition, development of competency, technology obsolescence, and process innovation ranked low in comparison, indicating that innovation is driven by operational concerns. According to Bryant (2015), the mining sector has not fully accepted the strategic role of technology and innovation in effective business planning and execution.
- Leadership – Divergent views within the organisation on digital transformation hinder the change and make it difficult to justify investments in digital technologies for digital transformation as it is seen as non-critical (Gao et al. 2019). Leadership must take responsibility for driving innovation in an organisation as they influence management style and can motivate employees to deliver on innovativeness (du Plessis and Pretorius 2017).
- Organisation and Governance Structures – Organisational culture can be considered a roadblock or a catalyst for digital transformation (Teichert 2019).
- Technological Constraints – Mining is a long-existing art with legacy processes and conventional structures (Amadi-Echendu et al. 2011). The legacy systems and IoT at mining sites are difficult to integrate. The nature of mining, its remoteness, and its operating environment reduce mining organisations' appetite for innovation (Bryant 2015; Gao et al. 2019). The legacy systems are also considered more robust, although they are not compatible with newer systems and cannot cope with high-volume data (Gao et al. 2019).
- External Environment – The external environment in the minerals resources industry relates to the health and safety, policies, and legislation, as well as the social responsibilities of mining organisations and the communities they operate in (Gao et al. 2019). Stakeholder involvement and engagement play a critical role in the technology adoption in the MR industry. Environmentalists may challenge innovations they consider unfavourable while unions or communities could advocate or counter development, they consider disadvantages.

3. Methods

A qualitative research approach was used for the study. Semi-structured interviews were conducted with eight respondents, who represented six commodity clusters. The research seeks to explore the factors that impact the adoption of digital technologies in South African mines. The purposive sampling technique was used with the following logic to identify the relevant respondents:

- A condition for the study was that the mines had to be active at the time of the research.
- The researcher identified these active mines by choosing organisations that were listed on the Mineral Council of South Africa's (MCSA) website as members.
- By selecting a possible sample from the MCSA members meant that the sample group would be aware of the MCSA's strategic priority of modernisation.
- The selected individuals had to be in a position that is directly responsible for introducing strategic initiatives in their organisation or be in a position that can influence the decision.

3.1 Sample Description

The respondents interviewed hold senior roles that have direct decision-making power or influence the adoption of technology in the operations they represent. Table 1 below details the roles the respondents held at the time of the interviews. Eight interviews were conducted in total. Two respondents, Respondent 1, and Respondent 7, manage their mine operations and actual production, while all other respondents' roles give them direct responsibility for overseeing technology planning, developments, and adoption of technology in their operations. The sample presented has enough industry knowledge and experience in the field of adopting new technology within their organisations (Table 1).

Table 1. List of respondents and their roles

Respondent	Role
Respondent 1	Senior Project Manager
Respondent 2	Project Manager, Technology
Respondent 3	Technical Lead
Respondent 4	Technology Manager
Respondent 5	Snr Technology Specialist
Respondent 6	Head of Technology
Respondent 7	Mining Manager
Respondent 8	Business Optimisation Manager

Figure 1 indicates the different commodity clusters the group of respondents represent in the South African MR industry. The commodities have been randomised to deter inference on the respondents' identity.

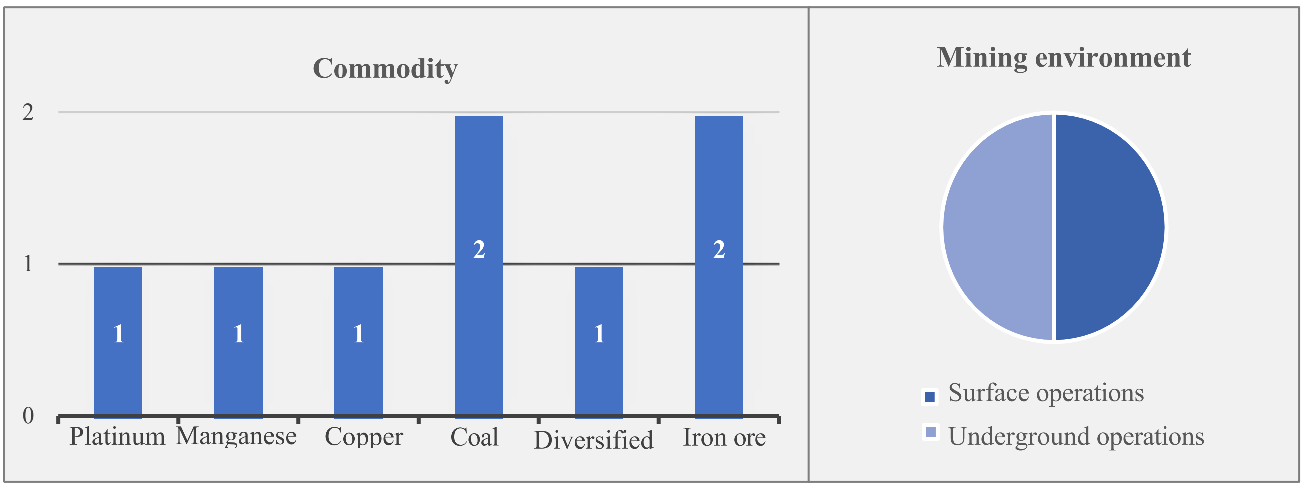

Figure 1. Commodity and mining environment represented by respondents

3.2 Data Collection

Semi-structured interviews were used for data collection in this study, and one-on-one interviews were conducted with key industry people. The questions are open-ended but define the area to be explored. The interview questionnaire was divided into two parts. The objective of the first part of the questionnaire is to develop context about the respondents' organisation (setting) and their understanding of the topic being interrogated. The second part of the questionnaire was to solicit detailed descriptions of the topic. Virtual interviews were then set up in Microsoft Teams. The interviews were recorded, and notes were taken throughout the sessions. Furthermore:

- An interview guide was employed to ensure that all respondents were asked the same questions for consistency and increased reliability in the data.
- The interview guide questions were pre-tested to check for double meaning and to avoid misinterpretation.
- All the interviews were recorded to test data analysis and interpretations for accuracy.
- During the interview, the researcher also took notes as a supplementary data collection method.
- The interview recordings were auto-transcribed verbatim using Microsoft Word Online.

- The researcher listened to the audio while reading through the transcriptions and edited them for correctness.
- Where the audio quality was poor, the researcher referred to their notes to help find meaning in the fragmented audio.
- The researcher then solicited the help of a professional transcriber to transcribe the audio to ensure that the researcher captured the interviewees correctly in the transcriptions.
- Subsequently, the researcher compared the initial transcriptions with the professional transcripts for cohesion.
- Only one interview had misaligned readings between the two transcripts due to fragmented audio.
- The recording of the interview in question was sent to the respondent together with the transcript to check for correctness.

3.3 Data Analysis
The transcription text was then coded. The coding of the data collected was completed using NVivo software, a computer-assisted qualitative data analysis software. A coding scheme was developed based on the Braun and Clarke (2006) strategy. The strategy follows a thematic analysis framework where codes are identified as part of the initial analysis of the data. For a theme to develop, two or more codes need to exist, identified by more than one respondent to be considered significant.

- If one code is identified, it will be classified as 'other'.
- Also, if more than one code is identified but from the same respondent, it will also be classified as 'other'.

The rationale for the criteria is that when the sub-theme meets the two-threshold level then it must be significant enough to be considered an insight. A thematic analysis was employed in this research study as the approach was useful for examining the perspectives of varied research respondents; it can "highlight similarities, and differences and generate unexpected insights" (Braun and Clarke 2006). The strategy is also useful when analysing large data sets (Nowell et al. 2017).

5. Results and Discussion
This chapter presents and discusses the results of the research study, which were generated from interviews with respondents from various mining organisations. The purpose of the research study was to explore the level of adoption of digital technology across mines in South Africa. This was achieved through three main objectives, and the results are discussed according to these objectives.

5.1 Objective 1 – The level of preparedness to adopt digital technology across mines in South Africa
To understand the level of preparedness to adopt digital technology across mines in SA, a series of questions were asked to the respondents that sort to firstly, build a picture of the respondent's 'organisational context' defined as the expressive characteristics of an organisation, including its scope, size, and management structure (Tornatzky and Fleischer 1990). Two of the eight respondents represent what is considered small-sized organisations that have no international footprint and no other operations within SA. One respondent is from a medium-sized organisation while the rest of the respondents come from large firms. The medium and large organisations all have an international footprint and run more than one operation in SA. The questions also sought to understand whether the respondents felt that their top management (leadership) supports the adoption of technology within the organisation. The respondents from the two small organisations responded negatively. 75% of the respondents mentioned that they have executive heads who focus on technology portfolios, and some also have technological project structures within the organisations. The respondents' understanding of digital technology was also tested. Most of the respondents seemed to understand the concept of digital technology because their organisations have defined digital technology within their process of adoption. The respondents in medium to large organisations provided a definition that evolved around data mining, data analytics, and data interpretation for better decision-making and the need to integrate their value chain.

In the global MR sector, companies are already harnessing the potential of digital technology by utilising end-to-end digitalisation, which may create significant differentiation and competitive advantage in the business. Further findings from the interviews indicate that, in the context of South African mines, companies are not concerned about the disruptiveness of digital technology in their operations. Respondents 1 and 2 agree that mining adopts technology very slowly. This perception is in line with Amadi-Echendu et al. (2011) that mining organisations adopt a reactive approach when it comes to technology applications. Whether large or small, most of the organisations represented view technology as having the potential to boost efficiency and production in the mining sector. South African mining organisations do not perceive an imminent concern for disruption, although they are not ignorant of its impact on digital transformation. In fact, they see digital transformation as an opportunity rather than as a disruption.

To test the mining organisations' preparedness for digital technology adoption, the concept of digital maturity was applied. As discussed in the literature review, digital maturity refers to an organisation's formation of specific capabilities to manage digital transformation (Rossmann 2018). When asked to rate their organisation's digital maturity on a scale of 1 to 10, all respondents fell into two groups of the three digital maturity groups developed by Kane et.al (2017). None of the respondents felt their organisations were in the early stages of digital development, with 50% of the respondents considering their organisation's digitally developing companies, giving a rating of 6, while 38% believe their organisations are digitally maturing, scoring 7 and above. Most respondents rated 6 and 7 because they think that they have created a foundation for digital adoption and upgrades but have not transformed into a complete digital mine that is fully automated. One respondent, however, did not provide a scalable answer. The respondents believe in the importance of digital technology across all levels of maturity. Interestingly, respondent 2 considered the digital maturity of the global organisation to be higher than their maturity in the South African context.

The findings showed that some of the organisations had adopted digital technology and had already created a platform for continual change and upgrade. Small firms that have not adopted any form of digital technologies are willing and believe they have the appetite to integrate digital technologies into their systems. For success, these innovation efforts need to be aligned with the organisation's strategy (du Plessis and Pretorius 2017). A strategy should be developed as an integral part of the organisation's digital technology adoption goals to be sustainable. A digital strategy provides a framework and a benchmark for the effective adoption of digital technologies within the mining industry. Six of the eight organisations indicated that they have a digital strategy in place. The responses corresponded to the company's size; and Table 2 summarises the findings.

Table 2. Summary of findings

Respondents	Organisational size	International footprint	Top Management Support	Digital Maturity 1-10	Digital Strategy
Respondent 1	Small	No	No	7	No
Respondent 2	Large	Yes	Yes	8	Yes
Respondent 3	Large	Yes	Yes	–	Yes
Respondent 4	Medium	Yes	Yes	6	Yes
Respondent 5	Large	Yes	Yes	9	Yes
Respondent 6	Large	Yes	Yes	6	Yes
Respondent 7	Small	No	No	6,5	No
Respondent 8	Large	Yes	Yes	6	Yes

5.2 Objective 2 – The drivers that influence the adoption of digital technology

The respondents were asked what they perceived to be drivers that influence the adoption of digital technology within their organisations. Respondents from firms with existing digital initiatives were further asked to explain the objectives of the digital initiatives within their organisations to understand the reason why mining companies would be motivated to adopt technology innovations. According to the respondents, all the initiatives adopted in these organisations were created by a business need. The study found that the development of a digital strategy within the organisations mainly had a productivity, safety, and efficiency motive, although not limited to these. These findings support the research that the top drivers for mining organisations' technology strategy are health and safety, environmental regulations, and production targets. All respondents mentioned that there is an urgent need for mining to improve efficiency and productivity and that these motivators were the main reasons for implementing digital technologies to modernise the mining value chain. With improved productivity, an increase in revenue is implied. Thus, improved cost or improved revenue were considered as a result of improved productivity or efficiency. Respondent 5 summarised this concept by saying, "across the mining sector, if your technology strategy does not touch on productivity improvement and safety then whatever you bring is not going to get a listen." It was further emphasised that technology should be appropriate for safety purposes, with an emphasis on value addition, rather than being employed or deployed for the sake of its existence. Mining companies would modernise their operations based on what value or benefit they would derive from adopting such change. Three respondents conceded that some technology has been introduced in the MR industry due to pressure from the South African Department of Mineral Resources (DMR) which acts as a regulatory body to administer and monitor that mining companies adhere to the Mine and Safety Act of 1996. Stakeholder involvement and engagement play a critical role in the technology adoption in the MR industry (Gao et al. 2019).

In summary, the main sub-themes, improved productivity, improved safety, potential to integrate the value chain, environmental sustainability, and improved corporate governance, were found to be drivers that influence the adoption of digital technology in SA mines. As predicted by Amadi-Echendu et al. (2011), factors like competition, development of competency, technology obsolescence, and process innovation rank low in comparison, indicating that innovation is driven by operational concerns.

5.3 Objective 3 – The barriers that influence the adoption of digital technology

The mining industry in SA has not fully embedded digital technology in its operations, and this, therefore, poses the question of barriers to the effective adoption of digital technologies within the industry. The study found that, amongst other hindrances, the greatest barrier that the industry is facing is the extensive capital investment required for digital transformation. For small firms, the main hindrance to adopting technology was the perceived cost of digital technology devices and the cost of maintenance as compared to the perceived value that will be gained by adopting digital technologies. Two factors are barriers to capital investment that impede the adoption of digital technology in South African mines, that is the cost of technology and the delayed return on investment. Most of the respondents were discouraged because of the perceived cost of technology in the mining space. Respondent 7's answer was the most straightforward when asked about their barriers to adopting digital technology, "Capital! We are not in a position to make big investments on that commitment." This supports the literature findings. Iacovou et al. (1995) believe that small firms tend to lack the resources that are necessary for adoption and other integration investments. The respondents identified a risk involved in introducing new technology. Small and medium-sized enterprises are likely to adopt technologies that have reached maturity levels due to the uncertainty of economic costs involved with each level of technological readiness, thus hesitating to adopt technologies in their early stages (Prause 2019). However, the research also found that in the South African context, mining organisations across all organisational sizes have a risk-averse approach toward adopting digital technology. Most of the technology strategies, as explained by the respondents, have a focus on mature technology or technology with a readiness level above five. Above all, 63% of the respondents found it difficult to contextualise digital technology to solicit buy-in. The respondents find it challenging to build a strong business case for digital technology because it is difficult to quantify its value. Digital technology is considered an intangible enabler which makes it difficult to have a communicable strategy that is clear, that people can understand, mainly driven by value.

Change management and skills capacity is another identified barrier from the analysis. Five of the eight respondents expressed with clarity that mine workers feared job losses. Due to that fear and some possible lack of skills and ability, workers are resistant to accept that change. The skills and knowledge demand of the workforce have moved from physical and routine to more abstract and cross-functional, with more IT elements. Technology has turned the role of the worker into automated procedures and computer programs by codifying their tacit process knowledge. All five respondents indicated that managing the change is a challenge that hinders the introduction of technology because, the more you streamline redundant and repetitive work, the more people feel that they are becoming redundant themselves.

Another barrier that 50% of the respondents expressed is the technology implementation, where technology suitability, technology infrastructure, and continuously evolving technology are considerable factors that impede the adoption of digital technology in South African mines. Gao et al. (2019) define this barrier, technological constraints, as one of the obstructions the minerals resources sector faces when considering technological change. Respondent 6 highlights that the organisation has various legacy systems, which they need to understand how to turn into future, capable, forward-compatible systems. The network infrastructures and reliabilities for mines, in terms of connectivity, are also a hindrance. The underground environment was stated by respondent 4 as a strong obstacle to adoption, noting that some digital technologies are not suited for the mining environment. The legacy systems and IoT at mining sites are difficult to integrate. Mining is a long existing art with conventional structures, it's remoteness and operating environment, reduces mining organisations' appetite for innovation (Bryant 2015; Amadi-Echendu et al. 2011, Gao et al. 2019). One barrier that makes up the final sub-theme has been identified by the data analysis as the burden to meet regulation and legislative requirements. Respondent 2, pointed to compliance requirements for adopting these forms of technology as daunting. South African mines operate under highly unionised labour environment with perceived political implications of adopting digital technology.

In summary, the third set of questions revealed the barriers that impede the adoption of digital technology in South African mines, according to the respondents: the capital investment required, technology readiness level, contextualising digital technology, change management and skills capacity, technology implementation, and regulation and legislature.

6. Conclusion

The results show that there is openness to adopt digital technology across various mining organisations. There is acknowledgment of the benefits that digital technology may provide, but there is frequently a lack of desire or capacity to design and implement the change management necessary to successfully integrate new technologies. Productivity, safety, potential to integrate the value chain, corporate governance, and environmental sustainability were identified as the main drivers to adopt digital technology, although not limited to these. The need to create safer work environments through safety improvements in the mining value chain is a critical value driver while the greatest enabler is top management. Various factors impede the adoption of digital technology, such as the cost of adopting and implementing digital technology and the inability to demonstrate a tangible return on investment in said technology. The low-risk appetite for SA mining organisations and low skill levels are also significant barriers to digital technology adoption. The study revealed that the medium and large mining houses that have adopted digital technology have, to a certain extent, embedded it into their systems and strategy and consider digital technology a high priority. In contrast, small mining houses find it difficult to create a conducive environment for adoption of digital technology because they have not prioritised it as something that can potentially add value to the business.

Mining organisations should focus on leadership attitudes as part of their change management strategies to boost the likelihood of adoption. According to the findings, mining organisation can also benefit from digital technology use across diverse employee groups by investing in training opportunities and skills development programs for long-term organisational learning, and upskilling. External stakeholder involvement is needed to meet the Mineral Council of South Africa's objectives of modernisation. Policymakers can contribute by incentivising for locally developed technologies, and how local innovation ecosystems respond to mining sector demands. Technology vendors should respond by adapting their digital technology to the South African mining context. And public–private collaborations should support digital technology adoption through infrastructure development.

The study indicates some correlation between the organisations's size and the organisation's level of preparedness to adopt digital technology. Organisations' level of preparedness to adopt digital technology was investigated using a self-reporting digital maturity measure. Respondents may overstate the digital maturity of their organisations due to social desirability. A longitudinal study examining how digital technology adoption evolves in small versus large organisations would provide more comprehensive insights.

References

Amadi-Echendu, J., Lephauphau, O., Maswanganyi, M. and Mkhize, M., Case studies of technology roadmapping in mining. *Journal of Engineering and Technology Management*, vol.28, no 1-2, pp. 23- 32, 2011.

Aslanova, I.V., and Kulichkina, A.I., Digital Maturity: Definition and Model, *Proceedings of the 2nd International Scientific and Practical Conference "Modern Management Trends and the Digital Economy: from Regional Development to Global Economic Growth"* Yekaterinburg, Russia, April 16-17, 2020.

Braun, V. and Clarke, V., Using thematic analysis in psychology. *Qualitative research in psychology*, vol. 3, pp. 77-101, 2006.

Bryant, P. 2015, *The Imperative Case for Innovation in the Mining Industry*, Clareo, 2015.

Dibaba, W. and Babu, R. P., The Role of Effective Integration of ICT in Education, especially in Primary and Secondary Education of Remote Settings. *International Journal of Advanced Research in Computer Science*, vol. 8, no. 9, 2017.

du Plessis, Marthinus J. & Pretorius, M. W, Towards a Better Understanding of the Key Elements Driving the Innovativeness of the Mineral Resources Industry: A Literature Review, *Proceedings of the Portland International Conference on Management of Engineering and Technology (PICMET)*, Oregon, USA, July, 2017.

Fitzgerald, M., Kruschwitz, N., Bonnet, D. and Welch, M, Embracing Digital Technology: A New Strategic Imperative. *MIT Sloan Management Review*, 2013.

Gannon, B., Outsiders: an exploratory history of IS in corporations. *Journal of Information Technology*, vol. 28, no. 01, pp. 50-62, 2013.

Gao, S., Hakanen, E., Töytäri, P. and Rajala, R., Digital Transformation in Asset-intensive Businesses: Lessons Learned from the Metals and Mining Industry, *Proceedings of the 52nd Hawaii International Conference on System Sciences*, Grand Wailea, Hawaii, January 8-11, 2019.

Iacovou, C. L., Benbasat, I. and Dexter, A. S., Electronic data interchange and small organisations: Adoption and impact of technology. *MIS Quarterly*, vol. 19, no.04, pp. 465-485, 1995.

Kane, G. C., Palmer, D., Phillips, A. N., Kiron, D. and Buckley, N., Achieving Digital Maturity: Adapting Your Company to a Changing World, *MIT Sloan Management Review*, 2017.

Lala, A., Moyo, M., Rehbach, S., and Sellschop, R., Productivity in mining operations: Reversing the downward trend, Available:https://www.mckinsey.com/~/media/McKinsey/Industries/Metals%20and%20Mining/Our%20Insights/Productivity%20in%20mining%20operations%20Reversing%20the%20downward%20trend/Productivity%20in%20mining%20operations%20Reversing%20the%20downward%20trend.pdf, Accessed June 2020.

Minerals Council South Africa., *Comprehensive Facts and Figures 2018,* Available:https://www.mineralscouncil.org.za/component/jdownloads/?task=download.send&id=787&catid=17&m=0, Accessed December 03, 2019.

Müller, J. M., Kiel, D., and Voigt, K., What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability. *Sustainability*, vol. 10, no. 1, pp 247-271, 2018.

North, K., Aramburu, N., Lorenzo, O., and Rego, A. Z., Digital maturity and growth of SMEs: a survey of firms in the Basque country (Spain). *Proceedings of the 14th International Forum on Knowledge Asset Dynamics*, Matera, Italy, June 5-7, 2019.

Nowell, L. S., Norris, J. M., White, D. E. and Moules, N. J., Thematic Analysis: Striving to meet the trustworthiness criteria, *International Journal of Qualitative Methods*, vol. 16, no.1, pp 1-13. 2017.

Prause, M., Challenges of Industry 4.0 Technology Adoption for SMEs: The Case of Japan, *Sustainability,* vol. 11, no. 20, pp. 1-13, 2019.

Remane, G., Hanelt, A., Wiesboeck, F. and Kolbe, L. M., Digital Maturity in Traditional Industries – An Exploratory Analysis, *Proceedings of the 25th European Conference on Information Systems,* Guimarães, Portugal, June 5-10, 2017.

Rogers, E. M., *Diffusion of Innovations*, 4th Edition, Free Press, New York, 1995.

Rossmann, A., Digital Maturity: Conceptualization and Measurement Model. *Proceedings of the 39th International Conference on Information Systems*. San Francisco, USA, December 13-16, 2018.

Salviotti, G., Gaur, A. and Pennarola, F., Strategic Factors Enabling Digital Maturity: An Extended Survey. *Proceedings of the 13th Mediterranean Conference on Information Systems,* Naples, Italy, September 27-28, 2019.

Sganzerla, C., Seixas, C., and Conti, A., Disruptive Innovation in Digital Mining. *Procedia Engineering*, vol. 138, pp. 64-71, 2015.

Teichert, R., Digital Transformation Maturity: A Systematic Review of Literature. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, vol. 67, no. 06, pp 1673-1687, 2019.

Tornatzky, L. and Fleischer, M, *The process of technology innovation*, Lexington Books, Massachusetts, 1990.

Young, A., and Rogers, W., A Review of Digital Transformation in Mining. *Mining, Metallurgy & Exploration*, vol. 36, pp 683-699, 2019.

Biographies

Leago T. SATHEKGE is a Mining Engineering professional who has over 10 years of experience working in the mineral resources industry in South Africa. She obtained her Bachelor of Engineering degree in Mining Engineering at the Faculty of Engineering, Built Environment & IT at the University of Pretoria in 2013. She later pursued her Master of Engineering degree in Innovation and Technology Management at the Graduate School of Technology Management also at the at the University of Pretoria which she earned in 2021. Her research interests include innovation, technology adoption and management and process improvement in the minerals sector. She currently works at a mining growth project in South Africa.

Marthinus J. du PLESSIS is a researcher and innovation strategy advisor at the University of Pretoria. He holds a Bachelor of Science Honours in Engineering Geology, a Bachelor of Science Honours in Technology Management and a Master of Science degree in Technology Management from the University of Pretoria. He has over 35 years of experience in the minerals industry with the bulk of his work in R&D, technology development and innovation. He has been involved with the Graduate School of Technology Management at the University of Pretoria as an innovation advisor, a part-time lecturer and study lead for Master degree students in Technology Management and Innovation while pursuing his PhD.

Hannelie NEL is an Associate Professor in Engineering Management in the Postgraduate Department of Engineering and Technology Management at the University of Pretoria, and a registered Professional Engineer. She holds a DEng Engineering Management, an MSc in Industrial Engineering, and a BEng in Chemical Engineering with over 25 years of experience in industry and academia. She served as Past President of the Southern African Institute for Industrial Engineering and is an Honorary Fellow of the Institute. She has received numerous international awards for her contribution to industry and academia, and her commitment to postgraduate engineering education and the advancement of women in engineering remains a lifelong passion.