Technology and growth in the South African mining industry: An assessment of critical success factors and challenges

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Abstract

The mining industry has yet to fully accept and embrace the strategic role of technology and innovation in successful business planning and execution. In this study, we empirically determine the factors that influence acceptance of technology solutions in the mining industry in South Africa, assess critical success factors influencing adoption of advanced technology in the South African mining industry, and explore challenges faced by the mining industry in South Africa in adopting advanced technology in its operations. Thematic content analysis is employed in the data analysis. Results show that critical success factors to the adoption of mining technology include learning culture, knowledge sharing, high labour costs, and behaviour of other firms in the industry; commonly identified challenges include inadequate engagement with external stakeholders, uncertainties, the cyclical nature of the sector, and high risk related to the adoption of unproven technology and performance systems focused on volumetric production. The study encourages mining companies to implement usage of technology. This can be properly done through regular engagement with the Minerals Council South Africa.

Keywords

technology, mining, South Africa

Introduction

Historically, South Africa's mining industry has been at the heart of the economy's development – given the country's competitive position as one of the most naturally resource-rich nations in the world (Antin, 2013). The South African mining industry and its sustainability are threatened by many global and local challenges. These challenges vary from high production costs, low profitability, labour unrest, to increasing demands by government (Lane et al., 2015).

Today, most deep-level underground mines are aging, with travel times to the face sometimes reaching an hour or more (Minerals Council South Africa (Minerals Council), 2021). Consequently, with increasing depth and distance from the shaft, actual drill time at the workface has contracted, accounting for greater health and safety challenges, shrinking production, and contributing to burgeoning costs (Minerals Council, 2021). Modernization of mines by improving on current technology will help to improve safety and health, facilitating the quest for zero harm. It will also contribute to increased skills development, employment, exports and revenue, and the knock-on effect on local communities (Minerals Council, 2021). The South African mining industry continues to battle economically, even though a minor recovery of commodity prices and higher production numbers have been seen. The last ten years have seen a continued sustained rise of operational expenses and capital development costs, and rapid decline in productivity (Bryant, 2015). This trend is not sustainable, especially against other key structural challenges, such as declining grades and more stranded assets.

Financial indicators are evidence of the ongoing weak trends; however, investors still expect higher returns and profitability margins. The need to focus on innovations is essential to deal with current operational challenges and convert them into opportunities (Guzek, 2015). Urgent adoption is thus a necessity to curb these deteriorating and unsustainable trends for the industry and for the economies that are thereby affected. Mining companies are required to provide a safe working environment for the health and safety of the employees, so it is of great importance that these factors are not viewed in isolation.

Rising productivity, alongside exploration, is the principal means by which mining can combat resource depletion (Humphreys, 2018). Modernization of mining has emerged as an enabler in redressing the decline of this critical industry, as it is said to have transformative effects in achieving safer work environments and improved efficiencies and productivity (Mavroudis, 2017). Organized labour unions do not see things in the same light, as they express concerns regarding the possibility of job losses as a result of new innovations.

The National Union of Mineworkers has been at the forefront of labour representation in the mining sector and has often used mass strikes to reach its goals (Antin, 2013). Contrary to this belief, modernization will contribute to increased skills development, employment, exports, and revenue (Minerals Council, 2021).

South African mining companies are, by definition, innovative, but there is significant room for the industry to more readily embrace the fourth industrial revolution (4IR) and innovation (PWC, 2010). Modernization necessitates mining, and the South African mining industry necessitates modernization as well. Over the last decade, South Africa's multi-factor productivity has fallen by 7.6%, and mining cost inflation has been 2% to 3% higher than general inflation, resulting in two-thirds of our output being in the upper half of the global mining cost curve (Department of Mineral Resources and Energy (DMRE), 2021). Mining output fell by 10% and mineral sales fell by 11%, highlighting the importance of modernization, not only for the mining industry's longevity, but also for social good (DMRE, 2021).

Given the highlighted importance of the mining sector in the South African economy and current challenges faced by the sector, on the one hand, and the slow uptake of technological advancement in South African mines, on the other hand, it has become critical that a study be undertaken to explore determinants of the adoption of technology in this sector. Although the study acknowledges previous studies on technology in the South African mining sector (Dayo-Olupona, 2020; Ntsoelengoe; 2019), it also notes gaps that were not filled: the former looked at emerging technology selection for only surface mines, without giving coverage to all mine types; the latter dwelled on factors necessary for effective adoption of modernization in the South African mining industry only, without evaluating the critical success factors and challenges. This study aimed to cover this lacuna.

Against this backdrop, the objectives of the study are, therefore, to empirically determine factors that influence acceptance of technology solutions in the mining industry in South Africa; assess critical success factors influencing the adoption of advanced technology in the South African mining industry; and explore challenges faced by the mining industry in South Africa in adopting advanced technology in its operations. The primary contribution of this study comes from the exploration of factors that influence the adoption of new technologies in South Africa, paying specific attention to the mining industry. Knowledge of such information allows the country to navigate through factors impeding the adoption of advanced technology in the sector and increase its rate of adoption. It also allows for formulation and implementation of critical policies in the sector, which will ultimately benefit the economy. As a result, it is hoped that the study's findings will have a positive impact on the development of a sustainable mining sector in South Africa and shed light on mining's significant contribution to the country's gross domestic product (GDP).

The rest of this paper is organized as follows: a review of the literature is followed by discussion of estimation techniques, results, and conclusions of the study.

Literature review

Mining dynamics in South Africa

Work to date indicates that modernization significantly extends mine life, preserves mining employment, improves safety and health, and allows mining of lower-grade ore bodies and deeper resources, which creates an environment conducive to 24/7 operations until 2045 and beyond (Minerals Council, 2021). A low-grade mine with a current conventionally mined life expectancy of some four years, using semi-mechanized methods, could extend operations to 15 years and, with full mechanization and 24/7 operations, to as much as 25 years (Minerals Council, 2021). Ultimately, without a shift in mining methodology, the industry will fail to profitably mine South Africa's deep-level complex orebodies. This could result in sterilization of resources, accelerated and premature mine closures, and job losses. Research suggests that 200,000 job losses by 2025 could indirectly affect 2 million people (Minerals Council, 2021).

South Africa remains one of the world's most significant mining destinations in terms of quantity and variety of mineral products produced (Technology Innovation Agency (TIA), 2012). It harbours the world's largest reserves of platinum-group metals (PGM), gold, and coal, and is ranked first in the production of PGM, manganese, vanadium, and chrome (Statistics South Africa (StatisticsSA), 2015). South Africa's rich endowment of mineral resources has played a vital role in the evolution of the economy. The mining industry was reported as the second-largest economic contributor in South Africa in 1980, with a contribution of 21% of GDP (StatisticsSA, 2017; 2022). According to a TIA report (2012), economic growth in South Africa will continue to be closely linked to proceeds from the mining sector.

While the role played by mining varies within different economies, the mining industry in many economies remains a key player in national growth, and South Africa is no exception. The presence of mineral resources in South Africa provides enormous potential for sustained economic growth and development. Generally, areas of major contributions of mining to the economy include foreign direct investment (FDI), revenue generation in the form of taxes and royalties, contribution to GDP, formal and informal employment, and sales revenue from exports (Bernard, 2018). Overall, mining contributes 1.5 million jobs and renders direct and indirect support to about 15 million people (Chamber of Mines, 2016).

The South African mining sector has, for more than 100 years, been considered a labour-intensive industry, using physically demanding manual drilling methods with blasting and cleaning on a stop–start basis, predominantly in narrow-reef hard-rock mining for gold, platinum, and chrome (Minerals Council, 2021). Although mining is still largely a labour-intensive process, the mining industry makes use of a wide range of technologies to reduce and prevent incidents related to health and safety. Central to curbing underground accidents is, as far as possible, the removal of miners from working-face dangers and in-stope health hazards. Where that is not possible, technology is directed at protecting employees.

Between 1984 and 2005, more than 11,000 mine workers died in South Africa, whilst in 2003, the death toll from mining accidents was approximately 270 fatalities. Consequently, an agreement was reached to reduce mining fatalities by 20% per annum (DMRE, 2017). The technology currently used represents incremental improvements, but offers significant contributions to making mines safer places to work. Furthermore, South African mining companies are collaborating with each other and equipment producers to develop better and safer working methods and technology (Minerals Council, 2021).

There are some 160 Mt of high-grade ore locked in underground support pillars that are accessible from current infrastructure, but at least double that could be mined below current infrastructure using appropriate technologies (Minerals Council, 2021). Once the accessible deposits are depleted, the challenge is to decide whether to go deeper or go somewhere else. In the past, going deeper was not possible due the cost and limitations in the technology. Today is different, with new advancements in technology (like robotics) and high commodity prices, so going further underground makes more economic sense, instead of transporting an entire fleet and infrastructure to a new location (Bravo, 2012).

Mineral sales represent a large export share in many economies, and South Africa is no exception. Through international trade of minerals, mining brings in huge foreign earnings from mineral sales and FDI into the South African economy. As stipulated by StatisticsSA (2017), revenue realized from both local and foreign mineral sales amounted to R 387 billion in 2015. Of this, coal contributed a significant 27%, followed by PGM with 25%, gold at 16%, iron ore at 10%, and the remainder by other minerals (Berman, 2017). Commodities with highest sales revenue contribution include PGM, coal, and gold. These three key minerals contributed 71% of the total mineral sales recorded in 2009, valued at R 171,876 billion (StatisticsSA, 2017; 2021). These minerals culminated in a 63% total contribution to minerals' GDP in that same year.

Owing to the small domestic demand for most of South Africa's mineral commodities, the mining industry is largely export-oriented (Bernard, 2018). Mining exports contributed between 40% and 50% of South Africa's total exports between 2001 and 2015, and are a major source of foreign exchange earnings (StatisticsSA, 2015). As stipulated in the Chamber of Mines (2016) report, mining exports amounted to R 320 billion in 2015. Nearly a third (27%) was accounted for by PGM, 21% by gold, 16% each by coal and iron ore, 10% was oil products, approximately 5% each for chromium and manganese ores and concentrates, and the balance by a few others (Bernard, 2018). Moreover, if beneficiated mining products are taken into account, then 60% of export revenue emanated from this broader category (Berman, 2017).

In 2022, South Africa's mineral production achieved a record high of R 1.18 trillion, up from R 1.1 trillion in 2021, which was the first time the industry topped the trillion rand mark (Minerals Council, 2023). This performance was driven by strong commodity prices, providing the domestic economy with a vital injection of higher taxes to bolster the fiscus, increase employment, and improve wages (Minerals Council, 2023).

According to the latest statistics released by the Minerals Council (2023), the mining industry is one of very few sectors in South Africa that is adding jobs in the prevailing economic climate. The sector created 15,500 more jobs in 2022, lifting total employment to 475,560 in the sector (Minerals Council, 2023).

Determinants of the adoption of advanced technology in mining: A review of theoretical literature

Literature reveals interchangeable use of the terms 'adoption' and 'diffusion', although these terms are quite distinct from each other. Adoption refers to "the stage in which a technology is selected for use by an individual or an organization" (Carr, 1999); diffusion refers to "the stage in which the technology spreads to general use and application" (Rogers, 1983). Therefore, while the term adoption is used at individual level, diffusion can be thought of as adoption by the masses. Adoption at individual and organizational levels leads to mass adoption, which is termed as the diffusion of technology. Hence, while looking into the evolution of research of technology adoption, we considered diffusion studies as well as adoption studies. Theories and models that have evolved for explaining adoption of technology are diffusion-based theories and the technology organization environment framework.

Diffusion of Innovation Theory (Rogers, 1983)

Research in diffusion can be traced back to the epic work by Everett Rogers in 1983, known as the Diffusion of Innovation Theory, which has been widely applied by researchers over the years. The main idea of the theory is that four elements influence the spread of a new idea: innovation, communication channels, time, and social system. The process of diffusion consists of five stages; namely, knowledge, persuasion, decision, implementation, and confirmation. It results in six categories of users: innovators, early adopters, early majority, late majority, laggards, and leap-froggers (Rajesh and Rajhans, 2014). The theory can be depicted as shown in Figure 1.

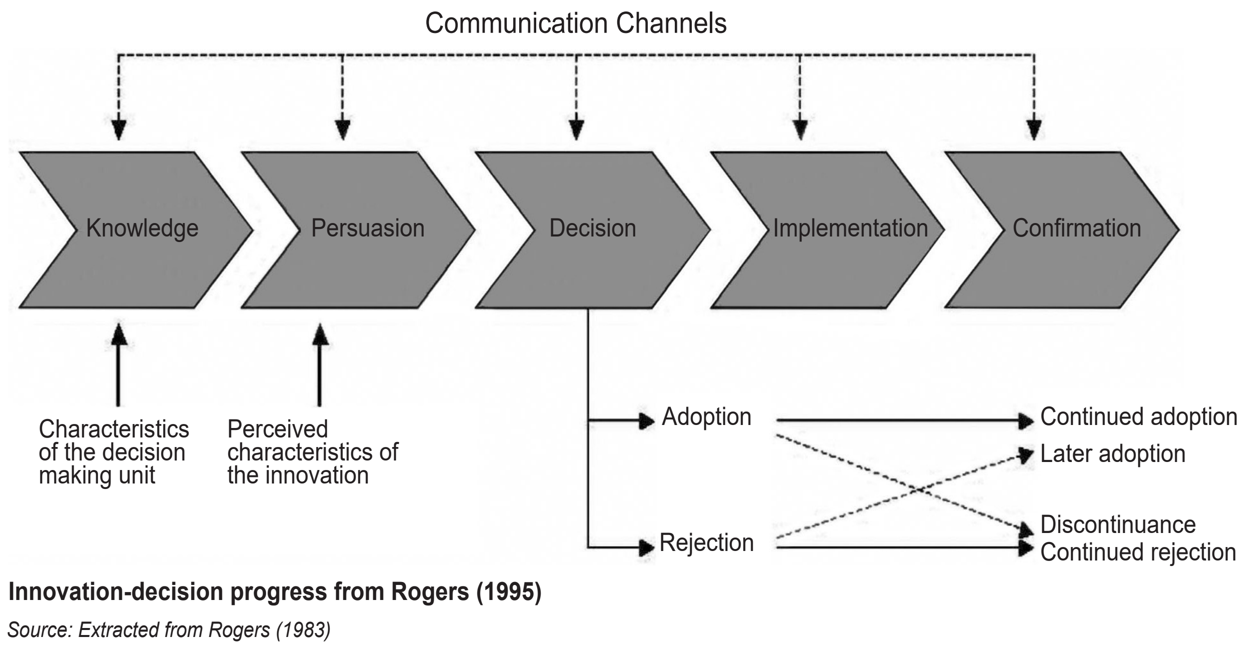

Figure 1—The Diffusion of Innovation Theory (extracted from Rogers, 1983)

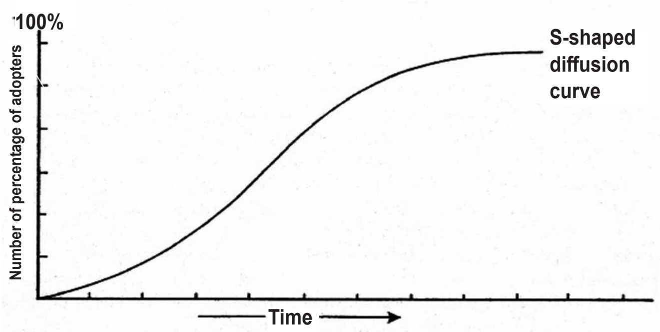

Figure 2—S-shaped adoption curve (extracted from Rogers, 1983)

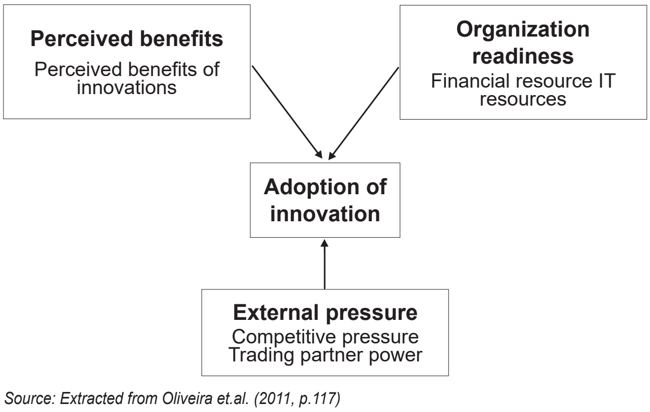

Figure 3—Iacovou, Benbasat, and Dexter model (extracted from Oliveira et al., 2011, p. 117)

The diffusion innovation theory provided the concept of S-shaped curve of adoption, also called the epidemic model of adoption. According to this curve, spread of infections among a population can be held as an analogy to the pattern of spread of a new technique or idea. According to this analogy, the rate of spread is initially slow; in the mid-range of the graph, the rate of spread accelerates, and finally the rate of spread tapers off, resulting in an S-shaped curve, as depicted in Figure 2.

The reasoning for such S-shape curve is that innovation has to initially come from outside the boundaries of the social system prevalent at that time. Eventually, the innovation is accepted by most members of the social system and the rate of spread declines. The S-shaped curve depicted in Figure 2 illustrates that there is a critical "take-off point", at which the slope of the growth curve becomes positive and the number of members who have adopted the innovation becomes so large that there are hardly any new members left to adopt it. According to Rogers (1983), this point occurs when 10% to 20% of the members of the social system have adopted the innovation (Rajesh and Rajhans, 2014). This S-shaped adoption curve applies to most innovations that arise from time to time. The phenomenal growth of the Internet over last 15 years is often interpreted by this law (Rajesh and Rajhans, 2014). Value of the innovation is enhanced for existing users as more and more people adopt the innovation.

Technology–organization–environment framework

The technology–organization–environment (TOE) framework was developed to identify three aspects of an enterprise's context that influence the process by which it adopts and implements a technological innovation; namely, technological context, organizational context, and environmental context (Oliveira and Martins, 2010). It is important to understand these different contexts and how they influence technology adoption. According to Oliveira and Martins (2010), technology context is described as technologies that are relevant to the organization, which can be found internally within the organization and those external to the organization. Technology can refer to equipment, processes, and information systems (Aizstrauta et al., 2015). The technology context can be applied to the mining industry. This because companies such as Rio Tinto mention being leaders in terms of technology in mining and having to develop technology internally, but also adopting technologies from suppliers (Rio Tinto, 2019).

According to Oliveira and Martins (2010), the context of the organization refers to measures that describe the organization, such as formal and informal processes, structures, communication processes, and size. These elements may differ for mining companies, depending on the product produced, their history and background, and how long the company has been in existence. All of these descriptive factors ultimately influence technology adoption. Environmental context describes the context in which an organization operates. This includes, for example, market structure, technology support, infrastructure, and government regulation. The theory of TOE is relevant to the mining industry because all context elements can be described to understand how these influence technology adoption.

Iacovou et al. (1995) described the characteristics that influence firms to adopt information technology (IT) innovations. According to Iacovou et al. (1995), there are three main circumstances that influence organizations in adopting IT innovation: the derived or perceived benefits that the company wishes to achieve, the organizational readiness, and pressures that are external to the organization. These three elements influence the decisions made by organizations. Figure 3 shows the association of the three elements. The perceived benefits can be described as the value drivers that influence company decisions to invest resources to achieve the desired goals. The perceived benefit for South African mining companies is that they remain competitive when compared with their global mining counterparts; the benefit for the Minerals Council is for mining to remain a significant contributor to the economy of South Africa.

According to Ernst and Young (2015), the mining industry requires transformation, and a set of value drivers needs to be defined as part of the transformation strategy. The model refers to organizational readiness being one of the elements, and to infrastructure and funding specifically allocated for technology adoption. Similarly, this factor can be related to capital funding and information system backbones required to enable technology adoption for the mining industry. The last elements relate to external pressures faced by organizations, which refers to competitive pressure. For South African mining companies, this relates to the global and local pressures that are outlined by Lane et al. (2015).

Mavroudis and Pierburg (2017) argued that information systems form the basis for implementation of any technology solution because communications is an enabler and a requirement for all the mining technology themes outlined. The adoption models outlined above discuss specific elements or characteristics that are important for adoption of technology innovation, specifically for the Information Systems industry. The following factors can be concluded to be the same for all three adoption models: organizational factors, infrastructure and financial resources, and external factors. Incorporating all three models suggests that technology adoption is a complex, inherently social, developmental process; individuals construct unique, yet malleable, perceptions of technology that influence their adoption decisions. Thus, successfully facilitating technology adoption must address cognitive, emotional, and contextual concerns.

Determinants of the adoption of advanced technology in mining: A review of empirical literature

Using a qualitative approach, Sager (2021) investigated challenges to implementing autonomous mining operations. Results showed that operational changes have the most impact on people, before process and technology, and are often not given enough attention in projects. Additional obstacles are the cyclical nature of the mining business, coupled with uncertainty about the remaining life of the mine. This impacts the long-term financial planning needed for an autonomous mining project, which is resource-intensive and of several years' duration (Sager, 2021).

Using data from 28 interviews with mining experts, Ediriweera and Wiewiora (2021) identified five environmental and four organizational barriers to technology adoption in mining. Inadequate engagement with external stakeholders, uncertainties, and cyclical nature of the sector are key barriers to innovation adoption. Other barriers identified include high risk related to adoption of unproven technology and performance systems focused on volumetric production. They also uncovered five enablers to overcome these barriers to achieve more successful technology adoption outcomes, including, among others, learning culture, knowledge sharing, and external stakeholder engagement.

Nasirov and Agostini (2018) studied the key issues (barriers and drivers) influencing the adoption of solar technologies in the Chilean mining industry from the perspective of mining actors. They found that implementation of automation may result in resistance from workforce and unions due to the fear that employees with lower skill sets may be made redundant at the 'mine of the future'. Furthermore, they found that mining managers may oppose the adoption of alternative energy sources to meet operational energy demands due to their general resistance to change; policy makers may have a similarly negative impact due to not offering incentives for use of renewable energies for mining operations.

Fujiono (2011) used agent-based modeling to demonstrate ways that innovations can be adopted in the mining industry. The agent-based modeling technique allows the modeller to design a system that consists of agents with unique characteristics (e.g., preferences, options, strategy, size). These agents behave and perform actions based on sets of rules that can be influenced by the aggregate behaviour of the system (Fujiono, 2011). The key finding from this study was that interaction between mining companies in the agent-based model can lead to emergent phenomena; in this case, the locked-in phenomenon. This finding suggests that interaction between diverse entities should receive more attention in the study of the collective behaviour of the mining industry towards an innovation, without ignoring the technological, economical, and environmental aspects of the innovation. In other words, the behaviour of other firms in the mining industry can be a barrier or enabler of adoption of technology. Hilson (2000) conducted a study on barriers to adopting cleaner technologies and cleaner production practices in the mining industry in the Americas. Using important regional examples, the barriers to adoption of the technologies were identified as legislative, technologic, and economic in nature.

Overall, of the various empirical studies reviewed, although they propose various critical success factors and challenges of embracing technological development as key to growth, they reveal the most common critical success factors as learning culture, knowledge sharing, high labour costs, and behaviour of other firms in the industry. Commonly identified challenges are inadequate engagement with external stakeholders, uncertainties, cyclical nature of the sector, and high risk related to adoption of unproven technology and performance systems focused on volumetric production.

Estimation techniques

This study adopted an exploratory research design to facilitate exploration of factors that enable or inhibit adoption of technology innovation solutions for the mining environment, particularly in the South African context. The exploratory research design was adopted because it helps in more efficiently understanding the problem.

The study took direction from Yin (2009) to employ the case-study research strategy, which assists in building in-depth and contextual understanding of the case in question using multiple sources of evidence. According to Baxter and Jack (2008), the collective case-study strategy is intended for gaining insight and understanding of a situation or phenomenon when more than one case is being examined. The results from a collective case study are robust and reliable (Baxter and Jack, 2008). This research study used a collective case-study strategy, aligned with the need to identify key enablers and inhibitors in a mining environment that are necessary for effective technology adoption in the South African mining industry.

Data collection

The target population for this study comprised all mining companies, mining-related organizations, and mining associations in South Africa. The study focused on four of the eleven commodity clusters to collect data (diamond, coal, iron ore, and platinum), purposively selected because these constitute the greatest proportion of mining activity in the country. The criteria used in selecting the mining operations was that they needed to have implemented or be in the process of considering a technology or any modernization concept for at least one piece of equipment in their value chain.

Using the purposive sampling technique, a sample of thirteen executives and senior managers from ten mining companies was drawn, from whom data were gathered using face-to-face or video-call semi-structured interviews, using an interview guide. The respondents held various positions, in 2021, responsible for implementing or introducing the advanced technology in the mining sector. All had experience ranging from 10 to over 20 years, and most possessed a degree at minimum. These statistics indicate that the respondents were highly educated and capable of implementing technology. Of the 13 respondents, five were females and eight were males; all were aged at least 18 years, with most being over 45 years of age. Following Saunders et al. (2018), who suggested that the sample size for qualitative analysis should comprise between five and 25 participants, the study's sample size of 13 was considered sufficient to realize the study objectives in a defensible manner.

Before commencement of the data-gathering process, the study received ethical clearance, with adherence to the ethical considerations of informed consent, confidentiality, and beneficence.

Data analysis

Data analysis was undertaken using Thematic Content Analysis (TCA). The data collected through online recordings were converted to written format and analysed using Atlas-ti software. Braun et al. (2014) stated that TCA is an essential tool to evaluate textual data. According to Braun et al. (2014), TCA comprises six phases: data familiarization, coding, theme scan, reviewing themes, defining and naming themes, and then writing up the information. To ensure validity and reliability, the same questions were posed to the respondents, which was an effective way to minimize bias in the data collected.

Results

The primary objective of this study was to understand the critical organizational factors that support or inhibit acceptance of technology solutions for effective adoption of modernization in the mining industry of South Africa. In this section, data gathered is analysed and discussed in an attempt to realize the research objectives. The discussion of results is organized according to the sub-objectives of the study.

Objective 1: Factors that influence the acceptance of technology solutions in the mining industry in South Africa

Information on the factors that lead to acceptance of technology by workers and the organization was gathered. These factors were found to be correlated to delivery of the organizations' strategic business goals in delivering value for all stakeholders in the short, medium, and long terms. Respondents had the opportunity to rank the factors in order of importance. Figure 4 summarizes these factors.

As shown in Figure 4, 54% (7) of the respondents outlined that if technology is implemented in the mining industry, cost can be greatly reduced because less manpower would be required, while 61% (8) stated that mining companies might introduce technology in the mining sector due to legislative requirements. The respondents suggested that mining companies must comply with the Mining and Safety Act of 1996; meeting the requirements of the Mining Act and the implementation of technology would increase levels of safety in the mining sector because human error would be reduced. All respondents stated that implementing technology would ensure environmental sustainability because mines would access underground minerals, whilst reducing environmental degradation and pollution.

In addition, 100% (13) of the respondents seconded the idea that technology would improve efficiency in the mining sector and increase rates of productivity. Furthermore, 85% (11) of the respondents suggested that investing in technology would enable the mining industry to unlock future resources that are hidden deep underground.

In terms of value drivers, most respondents across all commodity clusters cited value drivers as the most important motivator for organizations to commit to adoption of technology and innovative solutions to enable value delivery to their shareholders. These findings are in line with the theory proposed by Iacovou et al. (1995), who claimed that perceived benefit is one of the most important factors influencing organizations' adoption of IT innovation. Aizstrauta et al. (2015), Bryant (2015), and Lane et al. (2015) also support this viewpoint. The primary value drivers, according to the respondents, are safety improvements, efficiency and productivity increases, operational cost reductions, and environmental sustainability. Bryant (2015), Lane et al. (2015), Mavroudis and Pierburg (2017), Stanway et al. (2017), and others corroborate these major value drivers. These motivations are recognized as major benefits that inspire mining firms to change their ways of doing things by implementing technology.

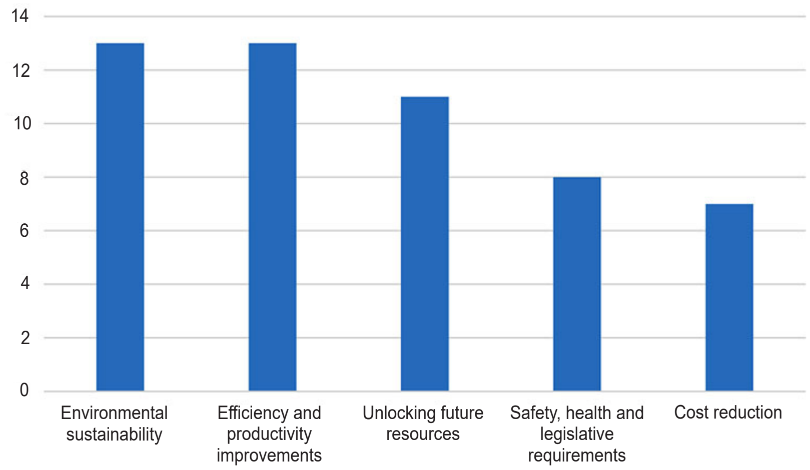

Figure 4—Factors that influence acceptance of technology

Across the commodity clusters, all respondents from mining organizations agreed that there has been an emphasis on improving safety and health conditions in the industry. The iron-ore cluster's Iron Ore 2 respondent and the platinum commodities cluster's Platinum 2 respondent both emphasized the need for safety improvements and highlighted that it is a regulatory necessity. Most respondents from all mining commodity clusters agreed with Iron Ore 1 respondent that mining businesses are implementing technology-based solutions with the goal of boosting productivity targets. Experts 1 and 3 confirmed this.

Most respondents mentioned high labour and energy costs for mining operators as the two main contributors of high operational costs. These cost drivers are confirmed by Lane et al. (2015) and the *Facts and Figures 2017* report released by the Minerals Council (2018). South African mining companies are driving efforts to reduce operating costs, in an attempt to improve profit margins and become competitive again. In addition, Iron Ore 1 respondent mentioned the unlocking of future resource value as a strategic value driver. This motivation for securing the future of mining comes as a unique finding when compared with the other respondents: most respondents were looking at surviving today, and not necessarily at securing future resources, given the depressed state of the economy. However, this contradicts this value driver, as highlighted by Lane et al. (2015), the Minerals Council (2016), and Jacobs and Webber-Youngman (2017), who noted that mining companies ought to secure future resources by investing in more-rapid discovery of resources and investigating new beneficiation methods to mine low-grade ores.

Most platinum commodity-cluster respondents mentioned that environmental sustainability was one of the drivers for implementing technology solutions to minimize their carbon footprint and water utilization. Platinum 3 respondent commented that energy costs were on the rise, and the company was therefore looking for technologies with less-intensive energy requirements. This statement was confirmed by Bryant (2015), who noted that energy inefficiencies have been alarming: only 12% of the energy from equipment contributes to delivering production; the rest is dissipated as heat or friction. The Minerals Council (2016) confirmed environmental sustainability as one of the drivers for modernization, and defined the scope for modernization in six areas, one of which is environmental sustainability.

Objective 2: Critical success factors influencing the adoption of advanced technology in the South African mining industry

Figure 5 illustrates the critical success factors that are needed to ensure that workers and organizations accept technology in their mining processes.

As shown in Figure 5, 100% of respondents stated that workers need to be trained, and this would equip them with the skills necessary to operate advanced machinery. These results are consistent with Bryant (2015), who propounded that technical skills are an important factor because this leads to efficient use of technology in the mining sector. All respondents suggested that there is need for good employer–employee relationships and executive sponsorship to ensure successful implementation of technology in the sector. In addition, all respondents suggested that there was need for investment funding to purchase advanced machinery and for training of workers: this would positively influence the acceptance of technology. These findings were confirmed by Bryant (2015) and Mavroudis and Pierburg (2017), who mentioned the need to spend capital in order to implement required infrastructure and, in the case of automation, that capital is also required for procurement of hardware to be installed.

Research and development was cited by 90% of respondents as an important tool to ensure successful implementation of technology and 80% stated that communication is essential when the organization is implementing technology: without communication, the adoption of technology would not be a success. The importance of communication was confirmed and emphasized by Rogers (1983), who noted this as being an integral element of diffusion of the innovation process. Most respondents referred to the role of the sponsor in taking the lead to actively share information with other executive members, which then filters through to the rest of the organization to create a mutual understanding (Rogers, 1983). Finally, 70% of respondents suggested that managers must develop strategies that would manage resistance to change.

Objective 3: Challenges faced by the mining industry in South Africa in adopting advanced technology in its operations

The respondents identified four factors as potentially inhibiting

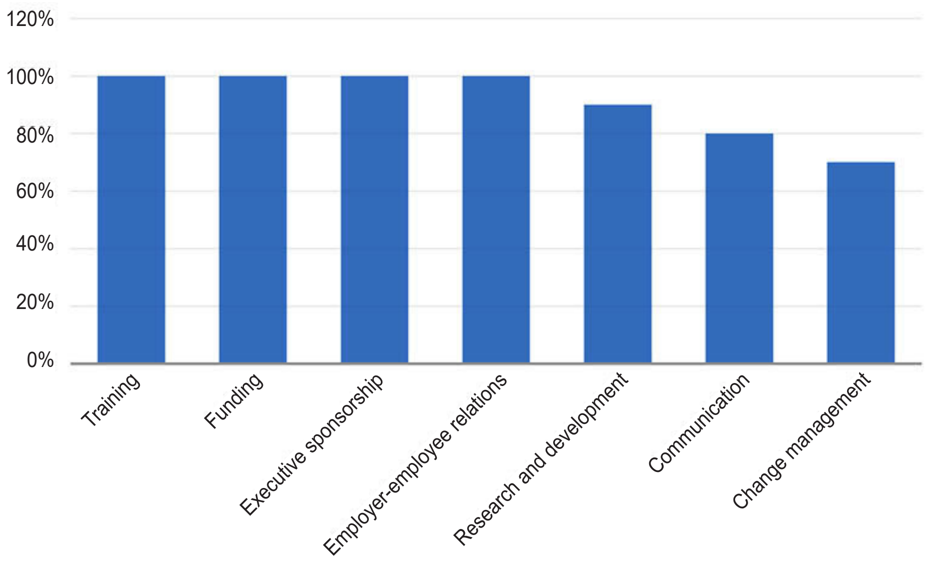

Figure 5—Critical success factors that influence adoption of advanced technology in the South African mining industry

and preventing technology solutions from being widely accepted, thus preventing mining companies from being effective in their modernization drive. These inhibiting factors are low technology readiness levels, capital funding, the lack of required digital skills necessary for executing technology functions, and behavioural change. The responses are displayed in Figure 6.

Technology readiness was cited by most respondents as the level of maturity of a technology innovation, either tested or implemented in a mining production environment.

Consistent with this objective, 70% of the respondents agreed that there was low impetus for companies to accept low readiness-level technology, which is associated with high risk of introducing an unproven technology into an operational business value chain. This was described as an inhibitor for technology adoption because companies avoid accepting technologies that have a low readiness level.

Another inhibitor is capital: all respondents and industry experts suggested that lack of funding was a definite inhibitor for introducing a technology solution. Some respondents suggested that companies cannot fully implement technology if they do not invest capital in automating or replacing existing equipment with autonomous equipment, which requires additional capital. Lack of funds is a significant impediment to implementing technology solutions in the mining industry, which, according to Bryant (2015), has received limited support due to the cost-cutting efforts.

Respondents also identified lack of the necessary digital skills as an inhibitor. According to Laubscher (2018), given the country's low level of qualifications, these skills are difficult to obtain, which explains the difficulty in addressing the unemployment rate. Sirinanda (2019) echoed these findings, stating that mining companies should invest in professional dynamic technology capabilities to better understand the intricacies of the industry. Approximately 80% of respondents also suggested that adoption of technology requires the right skills, so a lack of skills for its implementation serves as an inhibitor to effective adoption of modernization technology.

Two-thirds of respondents suggested that behavioral change can also be an inhibitor to the effective adoption of technology because there could be resistance to change amongst employees, who are the main implementers of a technology solution. According to Koul and Eydgahi (2018), technological change influences social and behavioural changes: if an individual's behavior does not change in response to these changes, acceptance will fail.

Conclusion

In this study, we empirically determined factors that influence acceptance of technology solutions in the mining industry in South Africa. We assessed critical success factors influencing the adoption of advanced technology in the South African mining industry and explored challenges faced by the industry in adopting advanced technology in its operations. TCA was employed in the data analysis. The results showed that critical success factors to the adoption of mining technology include learning culture, knowledge sharing, high labour costs, and behaviour of other firms in the industry; commonly identified challenges include inadequate engagement with external stakeholders, uncertainties, cyclical nature of the sector, and high risk related to the adoption of unproven technology and performance systems focused on volumetric production. Various factors influence implementation of technology in the mining sector, including the need to reduce costs, improve safety, discover new unexploited resources, and improve environmental sustainability.

Companies face various challenges in implementation of technology in the mining sector, so they need to mitigate this by appropriate strategies. From the results of the study, three key recommendations are proposed. Firstly, executives and senior managers in the mining sector should learn how other industries, such as agriculture, manufacturing, and healthcare, are adopting technology in their sectors. This could help the industry to overcome challenges they are facing by implementation of strategies used by other industries. Secondly, the Minerals Council is recommended to motivate mining companies to adopt technology in their activities and provide aid in the form of resources or information on how to best adopt technology. Thirdly, results of the study suggest that employees in the mining sector lack the necessary skills needed for successful adoption of technology. The government, alongside mining companies, is recommended to assist by offering training workshops to equip employees with the necessary skills. The government may also provide tax holidays or tax relief to firms that import advanced mining technology. This would reduce the cost of purchasing machinery, thereby incentivising mining companies to invest in advanced machinery.

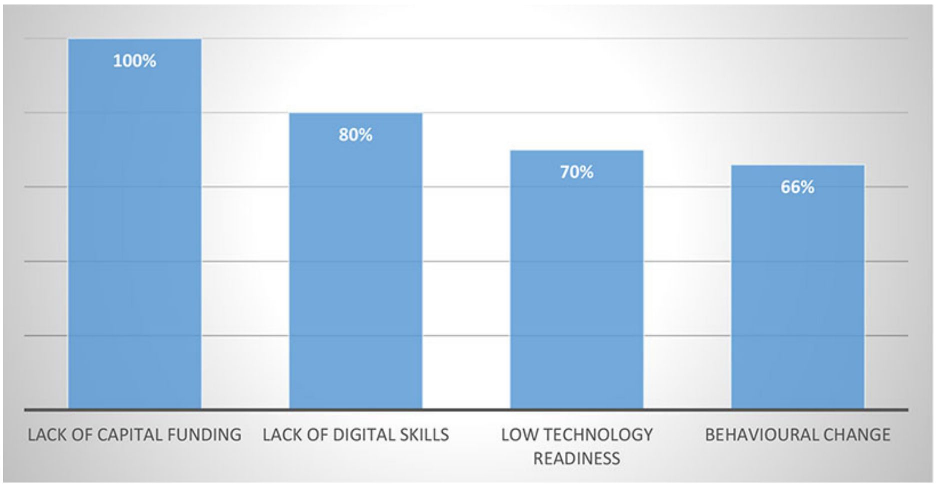

Figure 6—Challenges faced by the mining industry during the implementation of technology

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