Utilising Strategic Management of Technology and Innovation to Improve the Competitiveness and Effectiveness of Iron Ore Mines in South Africa

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Abstract

Currently, the mining industry is facing several challenges, which is why technology and innovation methods are so important. Deeper mining to access the ore, rising energy costs, more complex ore bodies, access to high-grade ore bodies, and social and geopolitical risks are just a few of the challenges that are putting pressure on the mining sector to control costs.

The main objective of this study was to investigate whether utilising the strategic management of technology and innovation could have a practical benefit in giving the mines a competitive advantage and contribute towards the sustainability of the iron ore mines.

Interviews were used to gather data, and prepared questions were sent to participants before the interviews. The themes that emerged after coding were the source of technology and innovation, improvement benefits, quality of product, and sustainability.

The results showed that the strategic management of technology and innovation was identified as the key enabler that can be used in iron ore mines to enhance competitiveness. This was revealed from the study when analysing the transcripts from the interviews. The participants believe that studying market trends to plan the executing stage and which technology to implement and where to implement that technology and innovative ideas hold the key to unlocking the value from the ore, boosting the business' profits, and addressing other production issues such as safety and production rate.

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1. Introduction

1.1. Background

There are two types of ore deposits in mining: economic reserves and uneconomic reserves. Economic reserves are reserves with the economic potential to be extracted profitably. Uneconomical reserves, however, are potential reserves considered to have future economic value. Due to economic conditions and the availability of technology to process the ore during exploration, uneconomical reserves are also referred to as sub-marginal ore deposits. Innovation, however, can facilitate the extraction of uneconomical ore deposits. This can increase the competitive advantage and make mining economically viable. Therefore, innovation is essential to running an organisation as it can provide a sustainable competitive advantage and contribute to long-term business success.

With the strategic management of technology and innovation, the best approach to the process of creating new value in the strategic management of technology and innovation is selected. This new value improves the organisation's financial outlook. By increasing the quality of the final product, it is possible to extract the best possible value and maximize profits when selling the product.

The current study aims to investigate the management of technology and innovation during the value-addition stage of the mining process and to evaluate the impact thereof on improving the economic viability of the mine. The study will focus on the following critical areas:

- Increased lifespan of the mines after implementing innovation,
- Improved quality of the final commodity, and
- Improved economics based on the implementation of innovation.

Mining companies gradually perceive innovation as an imperative to boost cost-effectiveness and guarantee the sustainability of operations; therefore, this study will examine the effectiveness of implementing technology and innovation in sub-marginal iron ore mines.

The mining sector is one of the critical pillars of the South African economy, contributing R78.1 billion in taxes, R480.9 billion to GDP, and employing 458 9954 people (Minerals Council of South Africa, 2022). Keeping this sector sustainable is good for the economy and the social well-being of the people of South Africa.

For mining activities to commence, mine management will have to explore the economics of mining a metal to assess the viability of the fundamental value and the returns when selling the final product. They should be able to enjoy the financial benefits and rewards of investing in mining activities in that area. Minedat.org (2022) defines marginal ore as "that part of the reserve base that borders on being economically producible at the time of determination. Its essential characteristic is economic

uncertainty. Included are resources that would be producible, given postulated changes in economic or technologic factors."

For commodities such as iron ore and manganese, activities have slowed down in recent years, with companies like Highveld Steel, TransAlloys, and AssMang all closing (Goldswain, 2016:1). This was due to the project being deemed uneconomical. This poses a question as to whether innovation could make these mines more profitable (Anglo-American, 2015:1).

1.2. Problem Statement

The mining of lower-grade iron ore has been regarded as the main cause of mine closures (Laurence, 2006). This is when the ore cannot be economically and sustainably extracted to be priced at a premium value. According to Clarke (2021), the significant difference in the price of different iron ore grades can impact the business's survival. Suppose the mining companies cannot develop and investigate different technologies and innovative ideas to lower the costs of value addition, minimize waste, and improve the product grade – in that case, it will be challenging for the mines to compete in the market and remain active. The main objective of this study is to investigate whether utilising strategic management of technology and innovation could have a practical benefit to sub marginal profitable mines in giving the mines a competitive advantage and contribute towards the sustainability of the iron ore mines.

The concept is to improve the final product (ore grade) so that more value can be extracted per ton. This should lead to improving the profitability of the iron ore mines. Thus, it should lead to prolonging the life span of the mine.

1.3. Research objectives

Stakeholders in the beneficiation value chain will be the primary focus of this study to address the problem statement and answer the research question. The main objective of this study is to investigate whether utilizing the strategic management of technology and innovation could have a practical benefit in giving the mines a competitive advantage and contribute towards the sustainability of iron ore mines.

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2. Literature Review

The reviewed literature was derived from various sources of secondary data, which included online journals, newspaper articles, published books, and research. Therefore, this section presents an

overview of the study variables and presents an empirical review of the research objectives. It also highlights the knowledge gap.

2.1. Process value addition

With innovation in the value addition stages of the run-of-mine (mined ore), mined low-grade ore heaps can be processed to produce a high-quality product without incurring additional mining costs. Sanchez and Hartlieb (2020:1385) believe that innovation has a vital role to play by offering solutions that are fit for the purpose of overcoming these challenges, such that the mining industry can flourish and become sustainable.

The marginal mines could be economically beneficial by improving the beneficiation process (West, 2011:66). Rötzer and Schmidt (2018:2) concur that the viability of exploiting low-ore grades is due to higher metal demand and outstanding innovation and not because of resource exhaustion. Through innovation, technically unfeasible deposits of Chilean copper have been exploited (Sanchez & Hartlieb, 2020:1385).

Seccombe (2018:1) reported that the process innovation currently being tested by the Kumba iron ore mine at Sishen mine for the low-grade ore can yield higher-grade products that can help marginal mines become profitable. Sanchez and Hartlieb (2020:1386) also highlighted the benefits of innovation in process efficiency improvement. The benefits are cost reduction and the ability to mine and beneficiate deposits from complex environments.

2.2. An overview of innovation

Innovation is a critical component of the economy's growth and the survival of businesses; without innovation, the economy would not be able to grow (Maier, 2018:135). Companies progressively realize that innovation is paramount to boosting profitability and safeguarding the sustainability of the business (Calzada Olvera, 2022:36-37). Broughel and Thierer (2019:3) as well as Diaconu (2011:128) believe that innovation is essential to growing the economy and human development. It also plays a critical role in the mining sector as an enabler to improve process efficiencies and cost reduction (Sánchez & Hartlieb, 2020:1397).

When applied correctly to any industry, and mining in particular, innovation could be the key added advantage (competitive advantage) to a company since, through innovation, wastage may be minimized, and processes streamlined. Different researchers and authors have defined the term and phenomenon of innovation in several ways while referring to the same thing. In business, innovation refers to when an organisation applies effort to produce something new that has never been produced before (Mendoza, 2015). Tseng (2014) further postulated that innovation refers to the action that an already existing organisation takes in a bid to bring novelty through new ways of production, operations, marketing, and

coming up with new products or services in order to meet or fit with the conditions in the business environment.

Within the same context, Vivarelli (2012) defined innovation as an initiative undertaken by organisations to introduce innovative ideas in their day-to-day business, products, and business processes different from those that are already in their system. The group of researchers further alluded that innovation is different from inventions, which means developing something new in this world; instead, innovation even takes the form of slight alterations or improvements on already existing organisational factors such as machines, products, or process factors such as products and processes. Mwaura, Gathenya and Kihoro (2015) also alluded that innovation refers to when an organisation continuously promotes the development of innovative ideas, which become the brainchild of new processes in the business, new products, and new markets. According to Damanpour (2018), innovation comes in several forms in businesses, such as new markets, new products or services, and new processes in doing business daily. It was further explained that businesses could adopt a combination of all the firms of innovation at the same time to meet their set targets.

Product innovation

WEF (2018) defined product innovation as the initiative by an organisation to develop new products in the market. This is primarily done to meet customers' ever-changing needs and expectations and to achieve a sustainable competitive advantage. According to Susman (2017), product innovation refers to the move by organisations to produce new products in the market to satisfy the customers' needs better than the competitors, thereby achieving organisational goals. Furthermore, Kollmann and Stöckmann (2014) pointed out that product innovation comes in the form of new product development (NPD), which is when an organisation produces new products that are distinct from existing products. The innovation might be new to the organisation or in the form of making alterations to an already existing product.

Market innovation

According to Diaconu (2011), market innovation refers to the effort made by an organisation to offer its products to a new market that it has never served before, for example, exporting to other countries. In this case, a new market is one that the organisation is serving for the first time, and this market may have existed before, but is being served by other organisations. According to researchers (Bala Subrahmanya, Mathirajan & Krishnaswamy, 2010), market innovation happens when an organisation takes its products or services to a new group of customers that it had never served before, even if it existed before and is being served by other organisations.

Process innovation

Obunike and Udu (2019) postulated that process innovation refers to the action by an organisation to change, alter or produce new ways of doing business, which is a step away from its status quo or traditional ways. According to Karabulut (2015), process innovation is shown by the organisation changing how it manages its inputs, how they are turned into finished goods, and how they are sold into the market (Karabulut, 2015). Collins (2019) also postulated that process innovation results from an organisation changing its production methods, management methods, and how they engage with the market to achieve effectiveness and efficiency.

Broughel and Thierer (2019:4) elaborated further by dividing innovation into three elements: (1) reduction in production costs, (2) improved product quality, and (3) production process improvement. Considering all different angles, innovation can be defined as exploring different ideas and developing an improved way of doing things, streamlining the production processes, and developing new products and services so that the livelihood of human beings and the environment can be improved (see Figure 1 below).

The three pillars that form the basis of innovation are *change*, the *process*, and *results*, as illustrated in Figure 1 below (Kogabayev & Maziliauskas, 2017:61). The development of the new process or the improvement can significantly bring about an added advantage to the performance of the business, or the improvement of the final product or the result that can bring about better performance for the customers and change the system holistically to adhere to the changes in the business environment for the product offerings.

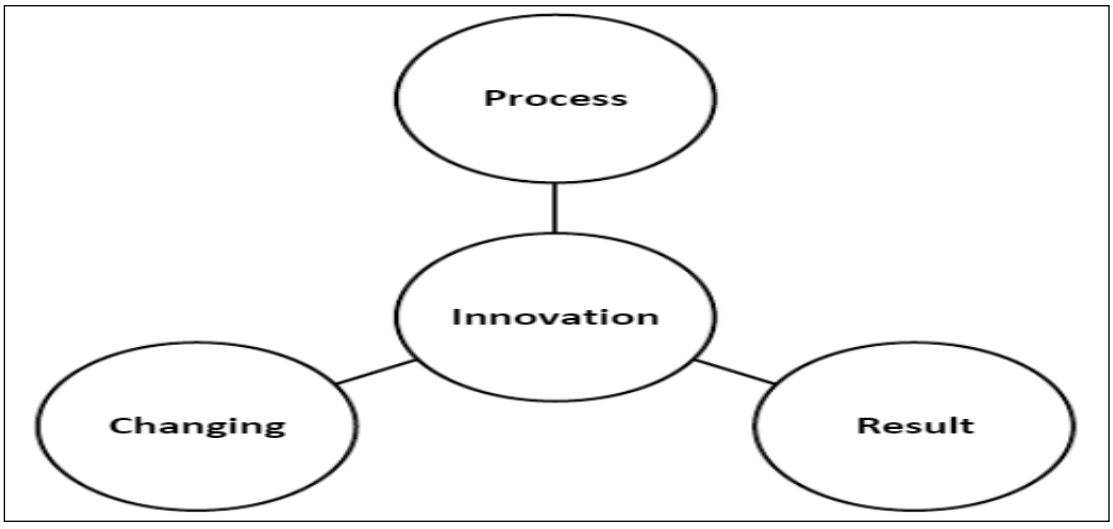

Figure 1: Pillars defining innovation
Source: Citing Šiauliai, Kogabaev and Maziliauskas (2017:61)

Mining companies are innovating to reduce operating costs (Delphi, 2017). Deep mines powered by conventional vehicles and generators have high costs for ventilation and cooling. Therefore, it is impossible to work at shallower depths without proper investments in both.

In addition to automation and digitisation, mining companies are trying to solve this problem by using electric vehicles, which is a result of innovation in the sector (Delphi, 2017). Different definitions from the literature were examined, and for the purposes of this study, the definition of Kogabayev and Maziliauskas (2017:61) will be used. It can be summarized as follows: Innovation is the application of a newly formulated concept into an existing or new product, service, or process.

2.3. An overview of technology

According to scientific researchers (Antonucci & Pianta, 2002), technology in business refers to the techniques, methods, processes, and skills adopted to produce services or goods or achieve targets. Technology is also referred to as the "art of science"; it represents the use of science or machines or robots to enhance operations in an organisation (Marrian, 2020). Other researchers (Edquist, Hommen & Mckelvey, 2001) postulated that technology refers to the tools, machines, or techniques that humans use to make their work easy, effective, and efficient. Technology is further defined similarly as using science for practical purposes in industries, leading to the development of machines and equipment by applying scientific knowledge (Gordon, 2019).

In the mining sector, technological innovations have been evidenced through automation, artificial intelligence, electrification, and digitalization, which have had a fundamental impact on the global sector (International Mines Ministers Summit, 2018). The technological innovations that have been introduced in the mining sector in recent times include:

- Haul trucks,
- Loaders,
- Autonomous vehicles,
- Automated drilling,
- Drones,
- Machine learning,
- Wearable technology, and
- GPS.

Technologies in the mining sector are increasingly proving to be commercially viable for companies as the risks associated with their adoption decrease and companies themselves face pressures to compete with technology leaders (WEF, 2017). According to Delphi (2017), labour costs are high for various mining companies across the globe, with significant wage premiums in the sector due to skills shortages and an ageing workforce. Therefore, it can be inferred that automated technologies provide companies

with leeway to remove staff from dangerous working conditions and replace them with advanced technologies such as robots. Furthermore, according to World Economic Forum (2017), with technological innovation in the mining sector, efficiency and productivity gains can be significant for those companies that operate in remote areas with high fuel costs. It was also suggested that technical costs are falling rapidly in many cases, which gives companies further opportunities to reduce and manage their operating costs in the face of volatile commodity markets in the mining sector.

Statistics have shown that the effects of technological innovation on mining are astounding and certain. WEF (2017) estimates that autonomous machines will be commonplace by 2025 in several sectors, including mining, and that having these machines operating 24/7 at high productivity levels and with lower personnel costs could add as much as USD 56 billion in value to the mining sector industry. The study by WEF estimates that adopting smart sensors could create approximately USD 34 billion in value for the global mining industry by enabling predictive maintenance, reducing downtime and equipment utilization, and lowering the frequency of health and safety incidents (WEF, 2017). Furthermore, the report also showed that digitisation, through improved health and safety, could save an estimated 1 000 lives and avoid 44 000 injuries in the mining sector globally (WEF, 2017).

Cosbey et al. (2016) postulated that it is essential to understand and mitigate the potential impact of technological innovation on the economy and community. It was stated that technological advancement might eradicate benefits of the communities, such as employment. There is a need for governments to make sure that a more equitable approach to technology integration is instilled in the mining sector by requiring the benefits of mineral development to be more distributed. According to Cosbey et al. (2016), there is also a need for governments to explore opportunities for increased, downstream value addition; modified fiscal regimes for improved revenue generation; the transfer of new knowledge and technologies from the private sector to state-run companies; and how mining infrastructure investments can be leveraged to benefit communities and other industries.

2.4. An overview of the profitability

Profitability is one of the significant financial performance indicators of organisations, and it refers to the money that the organisation is left with after covering all its costs and settling all its bills (Hazan, 2020). According to Hazan (2020), profitability is critical in measuring the performance of all businesses across all sectors as it shows the ability of a firm to pay out dividends to its owner or to achieve growth through re-investing part of the profits. According to Boone (2019), profitability refers to the ability of an organisation to earn a profit, which entails being left with funds to share among investors after meeting all their obligations. Bashir (2020) defined profit as what is left of the income generated by an organisation after paying all costs linked to revenue generation; for instance, producing a product and other costs linked to the conduct of the business. In support of the benefit definition above, Peters et al. (2021) stated that profit is the difference between the revenues incurred and the expenses

incurred by an organisation. The authors also pointed out that profitability is the primary goal of business investors as well as a top priority for company directors due to its ability to increase viability, growth and resilience. Therefore, it is very important to measure current and historical profitability and to predict the future profitability of an organisation in each financial period in order to implement a strategy to make the organisation profitable (Owen, 2020). Several methods have been proposed to measure a company's profitability, including the use of profitability ratios (Gitman, 2019). Profitability ratios emanate from a company's financial statements and are further classified into margins and returns (Gitman, 2019). The ability and capability of an organisation to translate sales revenue into profits at various stages of measurement are shown by profitability margins. On the other hand, ratios that show returns represent an organisation's capability to measure the firm's overall efficiency in generating returns for its investors (Bowman 2018).

Several profitability ratios are used to analyse the profitability of organisations, and these include:

- Return on assets,
- Return on equity,
- Gross profit margin, and
- Return on capital employed.

Return on capital employed (ROCE) is considered the most important measure of profitability because it measures the overall performance of a company (Van Horne 2017). ROCE shows the relationship between a company's earnings and, for example, the amount of capital used by the company. ROCE is calculated as:

Capital use = (Net income/Return on capital used) x 100.

It should be noted that the income used in ROCE calculation is income before interest and taxes. On the other hand, according to Van Horne (2017), employed capital includes equity and all long-term liabilities.

2.5. Strategic technology and innovation

According to Massuod and Hassan (2012), strategic technology and innovation management are the initiatives an organisation takes to craft and implement strategies that are aimed at instilling new technologies and innovations in the firm. Drejer (2006) suggested that strategic technology and innovation management refer to the strategies formulated and instilled by organisations to improve their technology adoption and innovation with the principal aim of enhancing performance and growth.

Mahmood et al. (2013) postulated that technology management is primarily focused on the interface of the organisation and the external technological environment. The researcher further states that technological items include R&D, technology status acquisitions, and technological policies. On the

other hand, innovation management areas are new product development, new process development, and innovation policies driven by the management and employees (Mahmood et al., 2013).

Other researchers (Burgelman, Maidique & Wheelwright, 2004:4) state that strategic technology and innovation management refer to the actions that are taken by the management of an organisation to put in place resources and make the decision to adopt new technologies and foster innovation. It can be alluded to that strategic technology and innovation management start from planning the technology adoption and innovation, which leads to setting technology and innovation goals. Burgelman, Maidique and Wheelwright (2004:4) stated that strategic technology and innovation management go through the distribution of resources, instilling control systems, motivating staff members, and checking progress to ensure that technology adoption and innovation goals are achieved in the firm.

In the mining sector, technological advancement has also been pointed out as a critical factor that improves the quality of work and the final products. Rio Tinto mine has adopted various technologies in Australia in recent years and achieved significant automation gains since its inception (Rio Tinto, 2017). The automation program in the company has helped to find innovative ways to extract minerals while at the same time reducing environmental impacts and improving worker safety. It has also helped the company to become the most automated mining operation in the world (Rio Tinto, 2017).

On the other hand, In Canada, Goldcorp's Eléonore Gold Mine has also adopted technological innovation to improve the quality of its workforce and enhance the quality of the final products. According to Goldcorp, strategic technology and innovation management refer to the formulating and implementation of strategies that help to enhance technology adoption and innovation in the organisation to improve corporate performance (Seppänen & Mäkinen, 2007).

Therefore, in this study, strategic technology and innovation management mean the business's process of adopting new technologies in the organisation and encouraging its staff members to be innovative. This is done with the primary goal of improving the performance of the company to gain a competitive advantage as well as sustainability.

2.6. Investigation how technology and innovation can improve product quality of work

The ability of technology to effectively detect defects during the production process has been regarded as one of the significant ways that improve the quality of final products in several sectors, such as the automobile sector, textile manufacturing sector, and food manufacturing sectors across the globe. A study conducted in the automobile sector in the United States of America showed that technology is extensively being adopted to check for defective goods during and after the production process (Carter, 2019). The study showed that some machines and robots are being adopted in the production line, and they help humans detect even the slightest defect in manufactured cars.

In the mining sector, technological advancement has also been pointed out as a critical factor that improves quality, as the company has been able to install a multi-service, secure IP network in the entire mine, enabling full Wi-Fi connectivity underground. The network includes voice-over-internet phones used for communication with staff throughout the mine. Workers, vehicles, and other heavy equipment are fitted with radio frequency identification tags, which transmit the person or equipment's unique ID number and location to the operations centre via the Wi-Fi network (Goldcorp, 2017). There is also the installation of sensors in vehicles, which send information about the functioning of the engine and systems and issue alerts when action is needed, for instance, maintenance (Goldcorp, 2017). Similar to Glencore at Onaping, Goldcorp is pursuing full electrification at its Borden Lake deposit, which has been regarded as a critical factor that enhances the quality of work in the mining company. The Canadian mining company has managed to make the mine the country's first all-electric operation and is also planning the world's first diesel-free hard rock mine, driven by the need to enhance quality improvement (Ross, 2016). According to Delphi (2017), the company aims to adopt a full range of electrified equipment, including load-haul-dump loaders, drills, bolters, and personnel carriers. The company, currently in the exploration phase, plans to design the mine to reflect the equipment it will use, with the ventilation and power systems representing the most dramatic break from a traditional diesel-based mining design.

Reducing operating costs and waste generation through innovation will help the company achieve its 20 percent increase in production across its operations by 2021. Cost is an important determinant of quality in the mining sector, and while electric equipment can be significantly more expensive than comparable diesel equipment, operational savings over time will make it more viable, as the mine goes to deeper depths to access the gold deposits (Delphi, 2017).

This means that technology and innovation are vital in enhancing quality in the mines as it is key to helping the employee communicate effectively in the shafts, have technologically advanced protective clothing, effective drilling, enable efficient transportation of ore as well as eradicating pollution, which all enhance the quality of the minerals extracted in the mining sector across the globe.

2.7. Quality of the final product to the profitability

To date, there has been no universal way to define quality, as some people perceive quality as meeting performance standards, some view it as meeting customers' needs, and some view it as satisfying customers (Tapke et al., 2020). Several researchers and authors have defined the term quality differently, depending on the role of people expressing it. Bagad (2018) states that the definition of quality has been put forth in several distinct categories, which fall under the following topics:

- Conformance to specifications,
- Fitness for use,
- The value paid for the price,

- Support services, and
- Psychological criteria.

According to Bagad (2018), conformance to specifications measures quality by determining how well the product meets the targets and tolerances determined by its designers. Furthermore, he stated that fitness for use aims at how well the product performs its intended use, while the value for the price paid assumes that quality is price sensitive. Additionally, Bagad (2018) states that support services provided with a product influence how a products or service's quality is judged. In this case, it has alluded that quality does not apply only to the product or service, but also encompasses the processes, people, and organisational environment associated with it.

In this study, the definition of quality adopted entails developing a product or service that can meet consumers' ever-changing needs and expectations (Tapke, 2020). In recent years, several studies have also been undertaken from different sectors, developing theories and literature regarding the impact of quality on firms' profitability in different global sectors. Researchers (Ittner & Larcker, 1997:532) have studied the computer industry and automotive sector in Germany, the USA, Japan, and Canada on the impact of quality improvement on corporate performance. The study adopted profitability as its dependent variable, and the findings showed that quality positively impacts profitability. The researchers alluded that an increase in quality helps to meet customer needs; therefore, sales revenue is derived from increased customer purchases, which enhance profitability if costs are kept low.

Chenhall (2017) conducted a study in the textile manufacturing sector in the United Kingdom, with findings indicating that improved product quality has a positive impact on the profitability and sales revenue of firms operating in London, lending support to the above study. These literature findings explained that when the products can satisfy the customers, the companies benefit through repeated purchases and attract new customers through word-of-mouth. It is also posed that this is essential in obtaining increased sales revenues and profits.

2.8. The technology acceptance model (TAM)

According to Ma and Liu (2006:59), the technology acceptance model, perceived usefulness, and perceived ease of use may be used to predict whether a technology will be accepted. Since its creation, the model has been tested in dozens of studies using a variety of applications, and as a result, it is now the most often used model of user acceptability and usage. However, the stated outcomes of the model have varying degrees of statistical significance, direction, and magnitude.

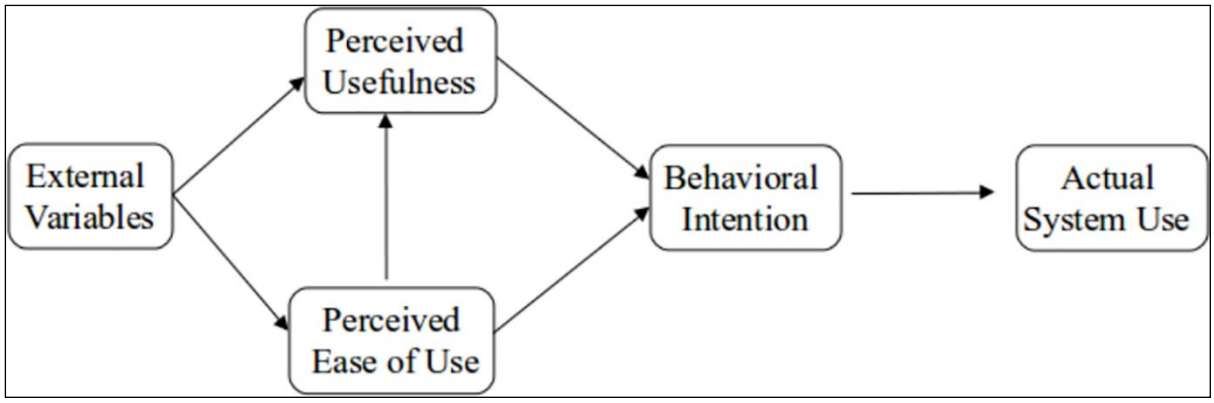

Figure 2: Technology acceptance model
(Source: Venkatesh & Davis, 2000:10)

Venkatesh and Davis (2000) concluded that people tend to use or not to use a system to the extent that they believe it will help them perform their job better (perceived usefulness) and also that the beliefs of the efforts required to use a system can directly affect system usage behaviour (perceived ease of use) (see Figure 2 above).

More formally, Venkatesh and Davis (2000:5) defined perceived usefulness and perceived ease of use as follows: Perceived usefulness is the degree to which an individual believes that using a particular system would enhance his job performance, and perceived ease of use is the degree to which an individual believes that using a specific system would be free of physical and mental effort.

Available technology in ore beneficiation

Unlike other business sectors, mining has specific technologies that are used to go about the company's core business, which is to extract miners from the ground. According to IMMS (2018), in their report, the latest technology trends in the mining sector show the existence of a compelling industry move towards sustainability. It has also alluded that digital technology works more efficiently and effectively than ever to deliver a truly safe, modern, and productive mine that meets the increased demand for mined materials, simultaneously exceeding customer expectations and global sustainability initiatives.

According to IMMS (2018), the global mining sector has been adopting various technologies to extract low-grade iron ore, and the technologies are expected to improve with time. Several technologies have been pointed out to be available in helping mining companies extract low-grade ore effectively. Some of the technologies are linked to the extraction of low-grade ore, and some are supporting technologies that play a significant role in achieving the same (Delphi, 2017). The report also pointed out that technology in the mining sector works hand in hand to extract low-grade ore regardless of other supporting technologies, such as information communication technologies (ICT) and drones.

According to IMMS (2018), the latest technologies used in the mining sector to meet corporate goals include spatial data visualisation, artificial intelligence (AI), high-power drills, geographic information

systems, and automated drones. Another author also pointed out the increase in the adoption of technologies in the mining sector to extract minerals, and among the most used technologies are artificial intelligence, drills, spatial visualisation, drones, and geographic information systems (Shook, 2018). According to Parkin (2019), mining is adopting vast technologies to extract iron ore in Germany, including drones, 3D visuals, drills, and geographical information systems.

Other researchers have also noted that robots are increasingly being used in the mining sector to extract minerals in dangerous areas or areas that are hazardous to humans (Ewing, 2018). The adoption of robots in the mining sector has been evidenced in developed and highly innovative countries across the globe and has been vital in helping humans stay out of danger.

On the topic of iron ore beneficiation in submarginal profitable mines in South Africa there are not much scholarly literature found. Bing AI found three recent sources. These are articles in Mineral Economics placed at the time of submitting this paper, in Kazakhstan based on minerals (Atakhanova & Azhibay, 2023)..

3. Research Methodology

This research examined how South African sub-marginal iron ore miners may increase profitability by strategically utilizing technology and innovative management. To create the groundwork for the research study, strategic management of technology, innovation, and the technology adoption paradigm were all thoroughly covered in the literature.

The methodology utilized for this study, the justification for the method used to perform it, and the strategy adopted are all covered in this section. Additionally, this section covers many steps of the investigation, such as participant selection, information gathering, and data analysis.

The strategy for this study was to investigate iron ore mines in the Northern Cape and Limpopo Provinces that extract value by processing the mined ore prior to sale to end users. Experienced individuals with expertise and understanding of the mineral beneficiation process were interviewed to gather knowledge of the criteria followed when the technology and innovation are being considered and the benefits thereof. This was done by the basic tenet of purposive sampling, which holds that participants should be selected from a variety of backgrounds for their opinions to represent these differences accurately and, as a result, produce superior research.

The study examined whether technology and innovation were strategically managed as critical enablers to unlock the value of ore throughout the beneficiation stage of mining to acquire a competitive advantage. The study also attempted to investigate the critical characteristics utilised to identify which technology and innovation should be applied based on the final ROI ratios.

Interviews were used as a data collection tool for this study, structured as individual, semi-structured face-to-face interviews with a set of prepared questions. The questions were designed to aid the researcher in understanding existing practices at the iron ore mine on how technology and innovation ideas are managed, the value provided by the ideas, and how they can be managed in the future. It was also critical to comprehend the concept of value addition to the product to maximise profit and continue to mine. For this study, the relationships between the money spent, value realisation, and sustainability were crucial.

Participants were recruited to represent viewpoints from both big and minor iron producers in South Africa. Considering the number of iron mines using the beneficiation step as a pre-sale value-added step, saturation was reached after a survey of seven participants.

Data collection methods

The study focused on iron ore mines located in the Northern Cape and Limpopo Provinces. Prior to the interview, a series of semi-structured questions were prepared to serve as an interview guide for this study. Other probing questions were asked to clarify key aspects that were clearly elaborated on during the interview and to assist with leading the discussion toward achieving study objectives. The following is the list (Figure 3) of semi-structured interview questions sent to the participants for them to prepare for the interview:

1. What is your highest qualification and the number of years of work experience?
2. In your opinion, how would you define innovation in the context of process improvement?
3. Do you collaborate with process development and equipment suppliers to develop innovative ideas or to create a meaningful improved production processes to beneficiate the ore?
4. How critical is your organization's budget for technology development, innovation, and R&D?
5. Does your mining company have a dedicated R&D department committed to investigating innovative or improved production processes to beneficiate the ore?
6. What criteria are used to approve new technology and innovation projects?
7. Describe some of your innovative ideas that made the running of the beneficiation plant smooth and how they benefited the company.
8. Does the application of technology assist in reducing wastage, improving production capacity, and product improvement?
9. How will the quality of the final product influence the price of the final product,
10. Do you think innovation and technology can successfully solve the profitability problem, and how can it be done?
11. How does the strategic management of technology and innovation affect the life of mine?
12. Will the implementation affect the type of ore mined?

Figure 3: Interview questions

The list in Figure 3 above was distributed to interviewees before conducting the interviews so that they could be better prepared to answer the question to the best of their knowledge.

Sample selection

Based on the number of iron mines that form the study population, the researcher chose a mix of significant producer and minor producers of iron ore to get a diverse overview from different ends of the spectrum.

An experienced process specialist was selected from each iron ore mine, irrespective of the size, and the requests to participate in the study were sent to the mines. This sample will accurately represent the population as there are 11 iron ore mines (two are in ramp-up and will not form part of the study) currently in operation in South Africa. Participants were interviewed in person.

Research process

The primary data for this qualitative study was collected through semi-structured interviews, which resulted in an enormous amount of data. Eminent miners have been sent an email requesting permission to conduct research on improving the profitability and sustainability of South African iron ore mines using the strategic management of technology and innovation.

Before the interview, an interview guide was provided to the participants, and the researcher requested that the interview be recorded to record the reasons after the interview. Five of the seven mines were in the Northern Cape and the other two were in Limpopo. Interviews lasted 15 to 20 minutes and were conducted at the participant's workplace. Notes were taken during the interviews to aid in data analysis. Participants were also allowed to speak during the interviews on topics unrelated to the interview questions.

Because of the large amount of data, encoding is an important step in high-quality data processing methods. Basic rules and transcription rules were followed to approximate the real version of the interview as closely as possible. After transcribing interviews, researchers analysed the data using Atlas.ti 22. Due to the vast amount of data, it was important to conduct a systematic analysis, especially during the conceptual phase of the study, to ensure the accuracy of conclusions. Atlas.ti is a very powerful working environment for qualitative data analysis, especially for text, visual and audio data. The program assists researchers in the process of data analysis, which includes analysing and interpreting text through coding and annotation (Smit, 2001).

3.1 Ethics

According to Klopper (2008:71), ethical considerations refer to the steps taken to ensure that all the rights of the participants are protected at all costs by making sure that informed consent is in place. The ethical approval from the institution is followed. Klopper (2008:71) went on to state the need for a researcher to provide relevant data on each of all the features and protect the rights of participants. The

informed consent form, the permission to conduct the study, and the confidentiality agreement were drafted and sent to the participants before the commencement of the research. Confidentiality is guaranteed. The ethics number from the NWU is: NWU-006877-22-S4

4. Results and Findings

4.1 Data analysis

Researchers used a three-step analysis by Miles and Huberman (1994:324) that included data reduction, data presentation, and conclusions. Without data coding, it is easier to recognize new patterns and maintain connections between concepts and underlying environments. Data reduction, according to Appleton (1995:995), involves the selection, focus, reduction, abstraction, and modification of data to derive meaning and understanding from participants' opinions. All recordings were recorded prior to reading each script multiple times to familiarize yourself with the content. Coding followed the interview transcription, and the codes were classified into categories and themes.

4.2 Themes, categories and codes

The data analysis identified four themes and they were classified into categories as indicated in Table 1.

Table 1: Themes and categories formulated during data analysis

Themes	Categories
Source of technology and innovation	Innovation definition
	Collaboration with equipment suppliers and process development companies
	Budget for technology and innovation
	Own R&D facility
	Project approval
	Successful projects implemented
Improvement benefits	Effects of technology application
	Successful projects implemented
Quality of product	Quality influence on the price of the final product
	Mine profitability
Sustainability	Life of mine under the strategic management of technology and innovation
	Ore types

From the transcripts of the interviews, the study revealed that association with key original equipment suppliers and process development companies creates an important and beneficial source of the latest development in the industry that the company may tap into to resolve issues that the mines are facing at that stage. It was also noted that the quality of the product has a role to play in ensuring that the mine is profitable.

4.3 Participants' background (trustworthiness)

A diverse group of participants was selected for this study, the main principle being to select participants with sound knowledge of iron ore processing (Figure 4).

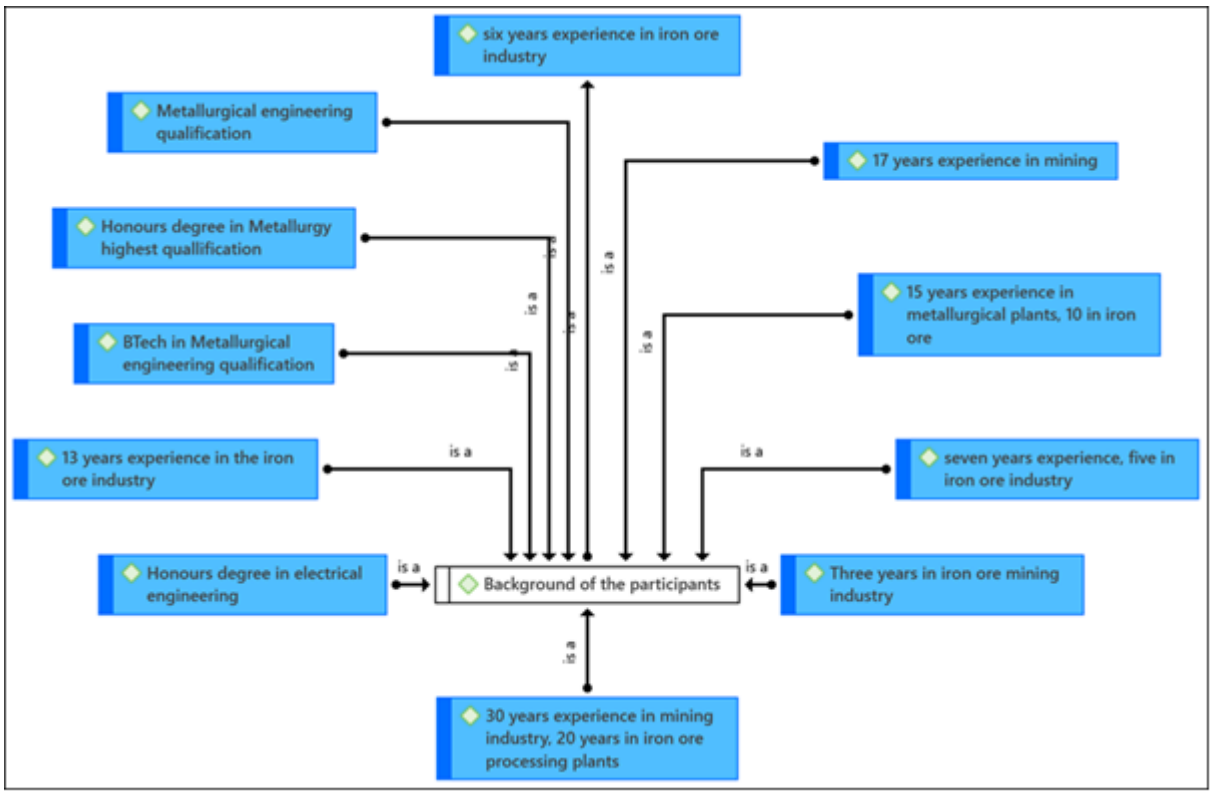

Figure 1: Network flow diagram of participants' background

One of these participants has 20 years of experience, but no metallurgical qualifications. The second participant is a qualified electrical engineer and has 13 years of experience. The rest of the contestants have several qualifications, ranging from a B-Tech diploma to an honours diploma in metallurgy. Although their experiences are different, they were involved in the beneficiation of iron ore.

4.5 Discussion of themes

With the deployment of the software Atlas ti, four themes stood out. These are discussed below.

Theme 1: Source of technology and innovation

The first identified theme examined how the participants understand the approach that the mines take when coming to innovation and technology. The responses were to give an understanding of the process followed, and the categories below dissect in depth what emerged from the interviews.

Innovation definition. Rich definitions of what innovation is within the context of process improvement were provided, which may be summarised as innovative ideas that positively influence the current process to increase product quality and process efficiency, consequently reducing waste generation, capacity, and production costs.

Collaboration with equipment suppliers and process development companies. According to the participants, it is essential to have that collaboration to enable the mine to tap into the knowledge and experience acquired by the suppliers over the years. With that, it becomes easier to develop a solution to problems currently experienced at the mines as they give advice and support on the equipment in use as well as other technology and equipment or amendments to the process they have been working on.

Some of the quotes from the participants' understanding of collaborating with other stakeholders are as follows:

"You will be sending quality product to low batch priced product, so I think it is essential to collaborate with your service providers."

"They help us in like interpreting what needs to happen on coming to data."

Budget for technology and innovation. The budget for innovation and technology is essential for growth, enhancing profitability, sustaining the business, and giving the mine a competitive advantage in the market. Participants believe it should be a substantial amount, in the region of 5 to 10% of annual income.

Some of the quotes from the participants take on the budget for technology and innovation are as follows:

"It is important to have quite a good percentage, I would say 10% of the company`s revenue should go to R&D."

"It is therefore critical to invest sufficiently into the budget of innovation and technology to reap the rewards of competitive advantage and also to sustain the business."

Own R&D facility. Based on the participants' responses, the companies are making use of established research and development facilities to conduct their research. However, they have teams responsible for innovative ideas and looking at the latest technology available to help the company solve its problems.

Some of the quotes from the participants on mines having their own R&D facility are as follows:

“They look at innovative ideas that can be even from other industry that could be beneficial to our industry.”

“Yes, we have an R&D facility but over the year have downsized quite a bit.”

Project approval. According to the participants, mines have a well-structured, multi-layered approach when it comes to project approvals. Financial viability is one of the key components that the adjudication is based on. Key economic parameters mentioned were the return on investments, the payback period, and the return on capital employed. Other issues that they look at are the ease of use for the new technology or process and also the safety aspect. Some of the quotes from the participants on the approval process of projects are as follows:

“Financial indicators of your return on investment, your payback period, the value-add or savings that you will get.”

“We have a rigorous process on approval of projects.”

Theme 2: Improvement benefits

The second theme revealed whether there are benefits that the mines enjoy due to the implementation of technology and innovation and the success of other projects implemented previously.

Successful projects implemented

From the responses, the participants indicated that there were recently successful projects with value-addition to the bottom line, such as the treatment of the final ore to generate value by using the latest technology in screening and also capacity creation by removing the bottlenecks.

Some of the quotes from the participants on the successful projects implemented by the mines are as follows:

“Introduced screen panels were Multotech and Bond Equipment developed called the retardation screen panels.”

Effects of technology application. Technology can minimise waste generation, increase plant efficiencies, and meet the quality demand of higher-grade specifications for our customers, according to the participants. Technology was applied successfully to the minus one-millimetre feedstock without experiencing any issues.

Some of the quotes from the participants on the approval process of projects are as follows:

“I think definitely, because you cannot beneficiate your fine ores.”

“The technology advancement has allowed us to create quality products in a fraction of the time previously required.”

Theme 3: Quality of product

The quality of the final ore product affects both the profitability of the business and the price, according to the participants. Quality also has a significant effect on the competitive advantage and the image of the business; it is important to consistently supply quality to the market.

Quality influence on the price of the final product. Participants noted that penalties are imposed on suppliers who do not meet the customers'' specifications, with their products being out-of-specification i.e., the quality of the ore. The higher the product quality, the more expensive it becomes; therefore, more customers will be attracted to your product and mine.

Some of the quotes from the participants on whether the quality of the product does influence the price of the product are as follows:

"The higher the quality of the final product, the more value can be extracted. The rule of thumb is always the higher the iron ore grade, the more expensive it becomes."

"You pay less penalties depending on some contracts we have."

Mine's profitability. With the latest technology and innovation ideas, the drive is to lower production costs by minimising waste generation, improving production efficiencies, and improving capacity at the beneficiation plant.

Some of the quotes from the participants on mine profitability are as follows:

"If managed strategically, the results will definitely impact the bottom line positively."

"It is crucial to do the project management effectively and that you don`t take too long or overspend."

Theme 4: Sustainability

The question was raised whether the use of strategic management of technology and innovation assists in sustaining the iron ore mine. According to the participants, it can be with the correct application and monitoring of the process.

Strategic management of technology and innovation is the right tool to prolong the life of a mine sustainably. It is also key to continuously improving the process to adapt to changing ore types and adjusting mining techniques. Mining companies should be at the forefront of utilising the latest technology and improved processes.

Some of the quotes from the participants on life of the mine under the strategic management of technology and innovation are as follows:

"It can result in reduced costs, increase productivity, improve working environment."

"If the process that we use is more efficient, we can be able to generate more income or maybe be profitable so that we can continually invest."

Ore types. According to the participants, innovation and technology are key to enabling a wide variety of ore to be mined and beneficiated successfully. From low-grade, fines (minus 1mm), and high-grade ore, all the different seams can be upgraded to the required grade and extract the maximum value from the product.

Some of the quotes from the participants on ore type are as follows:

"We can now mine low grade, high grade, different sizes through strategic management of the technology and innovation."

"We have different ore's that are mined here in our organisation."

4.6 Results of the qualitative analysis

After going through the process of data analysis whereby all the interview transcripts were loaded into the Atlas.ti software, the transcriptions were coded and themes emerged. The following were the results coming from data analysis:

- Management is crucial during the implementation of technology and innovation.
- Through strategic management of technology and innovation, the life of a mine can be prolonged successfully by different beneficiating types of ore seams at different sizes.
- The grade of the final product is linked to the final price the consumers are willing to pay, and penalties may be imposed if the grade of the final product is not met.
- Collaboration with the equipment manufacturers and the process developer is key in ensuring that the mine is on top of cutting-edge technology and innovation.

Provide descriptive statistics (if done) and details of the participants. Add additional statistics (ANOVA, etc.) and present the major findings and try and link your findings to the literature discussed.

Conclusion based on the analysis of the transcripts of the interviews (empirical findings)

Based on the data analysis of the transcripts from the interviews, it can be concluded that the production process can be streamlined to give the mining company a competitive advantage by minimising waste, improving the grade, increase the capacity of the plant. As a result, the production rate increases while dropping the production capacity. Embarking on improvement projects, utilising technology and innovative ideas should be strategic. The mine should collaborate with experts in the industry, such as the equipment manufacturer and process development companies. Strategic management of technology and innovation is the correct tool to utilise for improving the mines' profitability and sustainably prolonging a mine's life span.

5. Managerial Implications

Theoretical implications*:* This study will contribute immensely toward the empowerment of managers and owners in the field of technology, innovation, research and development, and economics of value addition in the mining sector.

Industry implications: The management of projects to improve value-addition to the beneficiation is key to the business's competitive advantage. In particular, in mining industries, iron ore mines are faced with the prospect of closing down operations. However, by implementing the strategic management of technology and innovation, it is possible to generate higher returns and continuously extend the life of the mine, i.e., a value-added economy that increases the profitability of mines indicate the managerial implications and provide some practical implications and recommendations.

6. Conclusions, Limitations and Future Research

The study's findings are presented and discussed in this section. The primary goal of this study was to determine whether strategic management of technology and innovation could provide a practical benefit in giving mines a competitive advantage and contribute to the sustainability of iron ore mines. The research's basis was constructed on the input of a literature study on South African iron ore, technology, innovation, strategic management of technology and innovation, and project financial viability calculations.

Four themes emerged from the study after the transcripts were loaded and analysed using Atlas.ti software. Topics include technology and sources of innovation, benefits of improvement, product quality and sustainability. The results were analysed to assess whether the research objectives have been met.

Conclusion

This study aimed to increase the profitability and sustainability of South African iron ore mines by utilising the strategic management of technology and innovation. This concept entails a phased approach in sourcing the latest technology and innovative ideas, timing the introduction into the process, and training the employees to prevent project delays during implementation. From the research proposal, the study was guided to solve the problem statement and, by so doing, meeting the primary and secondary objectives of the study. The research title was broken down into segments to understand the links behind various components and how they are intertwined. Technology and the latest technology currently available were discussed in depth, and the concepts of innovation, profitability analysis, technology acceptance model, and the quality of the final product were also discussed.

The strategic management of technology and innovation is a key enabler that can be used in iron ore mines to enhance competitiveness and effectiveness. This was revealed from the study when analysing

the transcripts from the interviews. The participants believe that studying market trends to plan the executing stage and which technology to implement and where to implement that particular technology. They also believe that innovative ideas hold the key to unlocking the value from the ore, boosting the business profits and addressing other production issues such as safety and production rate. There must be a solid relationship between the mines, process developers, and equipment manufacturers to share the knowledge and experience and problems experience from both sides for the mines to benefit from the latest developments.

With all the evidence presented in this current study, it can be concluded that, indeed, the strategic management of technology can be utilized to improve the profitability and sustainability of iron ore mines in South Africa. Continuous optimization of the process, waste reduction, and improved quality of the final product are the main pillars that will support the strategy. Collaboration is another key element that enhances the management process through shared expertise, knowledge, and experience. Based on the data analysis of the transcripts from the interviews, it can be concluded that the production process can be streamlined to give the mining company a competitive advantage by minimising waste, improving the grade, increase the capacity of the plant. As a result, the production rate increases while dropping the production capacity.

Embarking on improvement projects, utilising technology and innovative ideas should be strategic. The mine should collaborate with experts in the industry, such as equipment manufacturers and process development companies. Strategic management of technology and innovation is the correct tool to utilise for improving the mines' profitability and sustainably prolonging a mine's life.

Recommendations

It is therefore recommended that the budget for technology and innovation be reviewed to enable a continuous search for better ways to improve the process and sustain the business. Employees should be included throughout this process, as stated by the technology acceptance model. For organisations seeking to become more adaptive and innovative, culture change is a critical step of the process, and the management team should take the change management process to transform the workforce seriously. There is also a scope of extending this research to the mining side and applying the strategic management of technology and innovation in mining as well, and the combined holistic approach will further improve the mine’s profitability and sustainability. A thorough process on approving the projects should remain intact so that only projects that can bring substantial changes to the life of the mine can be approved.

Critical evaluation of the study

The study managed to answer the problem statement with the overall analysis of the study, that the strategic management of technology and innovation does give mines a practical benefit as a competitive

advantage and contribute towards sustainability. The response demonstrated that the participants shared one theme showing that the mine would be prolonged sustainably. Profitability and sustainability can be improved using the strategic management of technology and innovation, which was covered by themes 1, 2, 3 and 4 meaning that the primary objective was also achieved.

Suggestions for future research

The concept of strategic technology management plays a role throughout the mining sector, not only at the value-added level, but also at all stages, from surveying to mining. In the future, this work should be extended to other mines for the extraction of various commodities and analyzing the entire value chain.

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