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Use of Artificial Intelligence, Machine Learning and Autonomous Technologies in Mining Industry, South Africa

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KEYWORDS

Artificial Intelligence, Machine Learning, Big Data, Autonomous Vehicles and Autonomous technology, Mining Industry, Minerals

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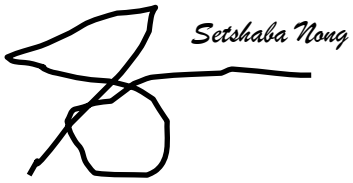
ABSTRACT

The mining industry plays a convincing role globally in driving various industries and contributing to economic prosperity. Locally, South Africa is known for having some of the largest minerals reserves in the world, although it is burdened with challenges inhibiting its progress and competitiveness. It is, however, expected that with application of AI, ML and AT will be able to revolutionise the industry, changing its fortunes, which will increase its competitiveness globally in the process attract investment and contribute to its longevity. As a result of these benefits, this research sought to investigate implication of AI, ML, AT technologies implementation in the mining industry of South Africa. The technologies are considered novel, especially in the mining industry, making employing qualitative study appropriate to assess how the implementation is received by the industry including perceptions and its potential impacts. Key findings of the study indicate that these technologies have the capacity to change the trajectory of the South African mining industry by dealing with issues of safety, costs, labour and efficiency. There is also an opportunity to pursue additional resources locked in pillars, by depth and dangerous working conditions due to geological complexities. However, capital costs, the nature of narrow tabular ore bodies and variability of various conditions are found to be some of the inhibiting factors for implementations of these technologies. As a result, there is no mine that has implemented any of these technologies as a primary means of production. This research will measure current perceptions of industry stakeholders and insights, role of government, mining companies, and equipment manufacturing response. The research highlight areas of impact and challenges that will contribute to strategy development in the process contributing to its sustainability. It is important to consider application of theory of constraint which is a detailed analysis which can assist mining companies in identification of inherent challenges so as to be able to respond appropriately with solutions offered by AI, ML and AT.

DECLARATION

I **Setshaba Nong** declare that this research is my own un-aided work with the exception of the references which are cited and acknowledged in the body of this study. The research is submitted in the partial fulfilment of the requirement for the degree of Masters of Management in the field of Digital Business at the University of the Witwatersrand, Johannesburg. This work is the original work and has not been submitted before for any degree or examination in this institution or any other University.

Name: Setshaba Phuti France Nong

Signature: 

Signed: Wits Business School

Date: 27th August 2021

DEDICATION

To my Mother, Sarah Ramathabatha Nong, thank you for your strength and support. Sello Nong, “Mokone wa dintšhi dikgolo”, you will for ever be gold and my hero for taking extra burden without complains. Your kindness, gestures of fortitude, and support in this challenging time are highly appreciated.

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To friends for your ever-encouraging words of wisdom during the gloomy period of my personal challenges. My class colleagues, thank you for sharing your life experiences and journey. Covid-19 might rob us of that physical stage, but virtually we shall climb it, celebrate and rejoice our sweat and tears.

Thank you to all the professors, lecturers and visiting lectures for not only giving us hard time, but also for purposeful inspiration and development.

To my supervisor, Dr Tebogo Sethibe, your effort, time and guidance is appreciated.

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LIST OF ACRONYMS

AI	Artificial intelligence
AT	Autonomous
BD	Big data
COVID 19	Coronavirus disease
CN	Network of communications
DMR	Department of Mineral Resources
GDP	Gross domestic product
ML	Machine learning
IT	Information technology
PGM	Platinum group metals
SA	South Africa
Stats SA	Statistics South Africa
Rsp	Respondent
TOC	Theory of constraint
OEM	Original equipment manufacturers
OT	Operational technology
PDS	Pedestrian detection system
USA	United States of America
VDS	Vehicle detection system

CHAPTER 1. INTRODUCTION

1.1 Purpose of the study

The purpose of this study is to investigate implication of AI, machine learning, autonomous technologies implementation in the mining industry of South Africa.

1.2 Context of the study

The mining industry plays an important role globally in development of infrastructure, health, manufacturing, agriculture and economies of the world. In the health sector, minerals are found to be essential (Awuchi Chinaza, 2020). Humans require minerals like calcium, phosphorus, potassium, sodium, and magnesium. The manufacturing sector also uses a plethora of minerals. Copper, nickel, silver, gold, platinum group metals, cobalt, and lithium, lead, tin, zinc, rare-earth metals, gallium, indium, iron, chromium, niobium, tantalum and titanium are some of the important elements used in manufacturing (Galos and Szamałek 2016).

In agriculture, Phosphorus and Potassium are mostly used for the production of fertilizers (Straaten 2007). With regards to economic contribution, the mining industry has given the world important metals like gold, which to this day is used as a monetary safety net in the form of federal reserves. According to Habashi (2016), most economies worldwide would collapse without coal as a source of energy. According to Keith and Sankar (2011), Coal fuels more than 40% of the world's electricity, where this figure is much higher in many countries, such as South Africa (93%), Poland (92%), China (79%), India (69%) and the United States (49%).

In terms of employment, more than two million people are employed globally by big mining companies, with multiply effect of up to five (Walser 2018). In some regions and countries, contribution to gross domestic product is particularly high, where noted figures of close to 90% are recorded in some countries (Ericsson and Löf 2019).

South Africa has some of the largest minerals reserves in the world, particularly in the case of platinum group metals (87,7% of world total), manganese (80%), chromium (72,4%), gold (29,7%), alumino-silicates, and accounts for over 40% of global production of ferrochromium, platinum group metals (PGMS) and vanadium. PGMs play a critical role in autocatalysis and pollution control in the automotive sector (Group Metals Platinum, 2020).

Mining experiences challenges globally. Lane, Guzek and Van Antwerpen (2014) indicate that declining ore grades at current depths also mean that mining companies have to mine ever deeper to reach new deposits, significantly increasing the cost of extraction. They also noted that mining at these depths introduces additional safety issues, due to the high risk of rock falls, flooding, gas discharges, earth tremors, and ventilation problems.

In South Africa, there are issues of antiquated mines, labour, inherent challenges of deeper resources, and lower grade discourages investment. The deepest mines are located in SA, where the Western Deep Level gold mine has reached an astonishing 4800m (Ranjith, Zhao, Ju, Silva and Rathnaweera 2017).

Other challenges include safety and health of persons in the mines. Mine fatalities in the past two years (2018 and 2019) totalled 132, with 4 853 occupational injuries, additional 1 974 deaths resulting from occupational related incidences and 7 968 recorded occupational diseases in the same period (DMR, 2020). The human impact extends to communities and families.

Labour unrest is one of the challenges facing the local industry. The worst case of unrest recorded in SA was the Marikana Massacre, with 34 miners killed and up to 78 injured (South African History Online, 2012).

Mining in SA has regressed in terms of contribution to the GDP and labour employment. According to StatsSA (2015), Mining contribution to GDP in 1980 was at least 20%, as compared to 7,3% recorded in 2018 (Langenhoven 2018). Also, Mining labour peaked at 780 000 people in 1987 (StatsSA, 2015). Accordingly, as of 2018, employment has decreased to 456,438 people (StatsSA, 2018).

1.3 Research problem

The mining industry unfortunately consist of inherent issues affecting safety of people, increasing mining depth which result in dangerous situations for workers while increasing costs. Some of the mines especially gold mines are old present set of challenges including rock burst, poor productivity and increasing costs. A study by Lane, Guzek and Van Antwerpen (2014) indicate that declining ore grades, increasing cost of extraction, and safety issues due to the high risk of rock falls, flooding, gas discharges, earth tremors, and ventilation problems affect the industry negatively. According to DMR (2019), in 2018 and 2019, fatalities totalled 132, with 4 853 occupational injuries, additional 1 974 deaths resulting from occupational related incidences and 7 968 recorded occupational diseases. Therefore safety, costs and its own difficult mining environment contribute to some of the problems affecting the industry.

Mining's contribution to the South African GDP in 1980 was at least 20%, as compared to 7, 3% recorded in 2018 (Langenhoven 2018). Additionally, mining labour peaked at 780 000 people in 1987 (StatsSA 2015). As of 2018, employment has decreased to 456,438 people. There figures shows the mining industry in SA in regression although expected to be a corner stone of the economy. Therefore the problem exist where there is obvious challenges which impact on safety, costs and an industry that is shrinking in its contribution GDP including employment.

A study conducted in the USA by Hyder and Siaun (2018) argued that one factor that can boost the growth of mining sector and make it more lucrative to investors is the application of AI, ML, and AT in the mining sector. They argue that with their intervention they will be able to improve capability, technological, economic and environmental outlook of the industry.

However, Lottermoser and Barnewold (2020) noted that analysis of 158 active surface and underground mines has shown that mines show a poor uptake of the AI, ML and AT technologies. The findings is difficult to fathom due to many benefits associated with these technologies.

It for these this reason that this study is essential in exploring broader interaction with the actual environment application, where design, people and implementation challenges are of concern through empirical qualitative study to explore this phenomenon. The study will be able to highlight the broader context of use of AI, ML and AT in SA.

1.4 Research objectives

The main objective of this research is to investigate implication of AI, ML, AT technologies implementation in the mining industry of South Africa. Therefore the emerging sub-objective are as follows:

- ◊ Sub-objective 1: To investigate potential uses of AI, ML and AT technologies in mining industry
- ◊ Sub-objective 2: To investigate some of the major impacts of implementing these technologies
- ◊ Sub-objective 3: To investigate main hurdles and challenges in implementing these technologies
- ◊ Sub-objective 4: To investigate implementation impact of these technologies on workforce demographics and worker relations and availability of jobs

1.5 Research Questions

Based on the literature review the following research questions will be probed further as they are designed to get the relevant data:

- ◊ What are the long-term strategic decisions being made in support of AI, ML and AT?
- ◊ How do you see the AI, ML and AT technologies changing the future of mining organisations in South Africa?
- ◊ What are the potential uses of AI, ML and AT technologies in mining industry?

- ◊ What are some major impacts areas of implementing these technologies?
- ◊ What are the main hurdles and challenges in implementing these technologies?
- ◊ How do the implementation of these technologies affect the workforce demographics and worker relations and availability of jobs?

1.6 Significance of the study

The study is significant as it will contribute to insights of the impact of AT, ML and AT in the mining industry and the adaptation. The study will further highlight areas of implementation and perceived benefit for specific mining environment either on surface and or underground. A paper by Grobler (2010) conducted a decade ago on AT, has highlighted that these technologies can be implemented successfully in a mine. However, beside this project, there are no other mines that have implemented these advanced technologies, despite the benefit in SA. Therefore, the study will further explore this negative adoption of this technologies. The negative impact on employment will also be dissected to explore opportunities and feasible approaches to stakeholder acceptability.

In terms of academic knowledge, the study will contribute to future mining management strategies, projects implementation, and consideration of adoption of advanced technologies during feasibility studies and change management for operating mines. The purported benefits associated with application of AI, ML, and AT will be highlighted and their impact on operating environment.

1.7 Delimitations of the study

This research is conducted in SA mining industry, with a sample derived from five classes of mines based on common characteristics and practiced mining methods in surface and underground. The sample size chosen is expected to sufficiently cover phenomenon and address the research questions while avoiding saturation. Therefore, for the purposes of this study, 14 respondents were interviewed for the research and satisfy the requirement for a qualitative study approach. For phenomenological studies Creswell, (1998) recommends

five to 25 respondents. The industry currently have limited data due to infancy of applications of AI, ML and AT.

1.8 Chapter Outline

The outline of the study is made up of five chapters. **Chapter 1** introduces the mining industry, then offers context of the study and then highlights research problem. It then looks at the objectives, significance of the study, delimitations, study definitions, assumptions, and finally, the chapter outline for the Research documents.

Chapter 2 submits the introductions, theoretical framework and expand literature review on prior studies in associated industry and mining sector, and finally the research questions are highlighted and finally concluding remarks are postulated. **Chapter 3** provides the methodological approach followed by sequentially by research approach, research design, data collection methods, population and sample, the research instrument, procedure for data collection, data analysis and interpretation, limitations of the study, validity and reliability, demographic profile of respondents and finally ethical considerations. **Chapter 4** presents the results of the study tested and any correlations. **Chapter 5** discusses the study's findings in comparison with existing theories and literature. It provides the limitations, theoretical and practical contribution makes suggestions for future research and recommendations and conclusions.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to review prior studies on AI, ML and AT in comparative industries to mining and also in the mining industry. A theoretical framework is established to anchor the study. A theory of constraints has been found to be the most suitable to support the research. The chapter is organised as follows: theoretical framework, definitions, and prior comparative industries studies (AI, ML and AT), prior studies in mining (AI, ML and AT), and then finally, concluding remarks.

2.2 Theoretical Framework

For the purposes of this study, Theory of Constraints (TC) has been found to be suitable to anchor the research. It is defined as a management philosophy which is focused on weakest rings in the chain to improve the performance of system, as described by Simisit, Gunay and Vayvay (2014). According to Goldratt and Cox (1992), TC is a five stepped continuous approach consisting of the following steps:

Step 1 - Identify constraints: The process of strengthening weakest link in the chain begins with the identification of the constraints. The constraint will be the most single part of the process that limits the rate at which the goal is achieved. It is therefore crucial to ensure proper identification of the constraint. The constraint must also be measurable to ensure follow up process addresses the correct issues.

Step 2 - Develop a plan to overcome identified constraints: Once Step 1 is completed, improvements must be done with existing resources without additional capacity. The second step is designed to deal with maximisation of current resources in order to overcome the identified constraints.

Step 3 - Focus resources on accomplishing Step 2: Make sure all other activities in the process are aligned with the resolution of the constraint. The process activities will be subordinated to ensure that they are aligned with and truly support the needs of the constraint.

Step 4 - Reduce effect of constraints: If the constraint remains, think about what else can be done to address it, such as adding extra resources. Step 4 allows for additional resources to deal effectively with the constraint. Additional resources can be implemented including use of technology to eliminate the constraint.

Step 5 - When constraints are overcome, it is necessary to go back to identify to new constraints. This process is a continuous and recognises that new constraints are identified and eliminated, where, as a result, the process will start from beginning again to Step 1. It gives flexibility to deals with inherent new inherent constraints, which will then subjected to the same process as well.

The five steps are a continuous improvement cycle. Therefore, once a constraint is resolved the next constraint should immediately be addressed. The process allows use of resources, where required, so as to change the status of the constraint. It also takes cognisance of the fact that the new or inherent must also be subjected to the five-step process.

This theory is relevant to this study as it provides a systematic and structured approach in dealing with challenges identified in the mining industry through literature review. The challenges and impacted variables include issues of safety, grade, and antiquated mine, depth, poor efficiencies and costs. For the purposes of this study, there are two mining environments, viz. surface, and underground.

TOC employs comprehensive analysis to identify challenges which are limiting in nature and prevent organisation from reaching their ultimate goals. The nature of TOC therefore is to look at the whole process and systematically eliminate constraints until they are no longer a restraint to achieving goals.

In applying TC, it is expected thus that due to its broader imperatives, better insight of the challenges will be understood in the process create solutions which will add value. The process is continuous hence newer inherent constraints will be detected an eliminated. The diagrammatical framework is indicated in Figure 1 and appendix E.

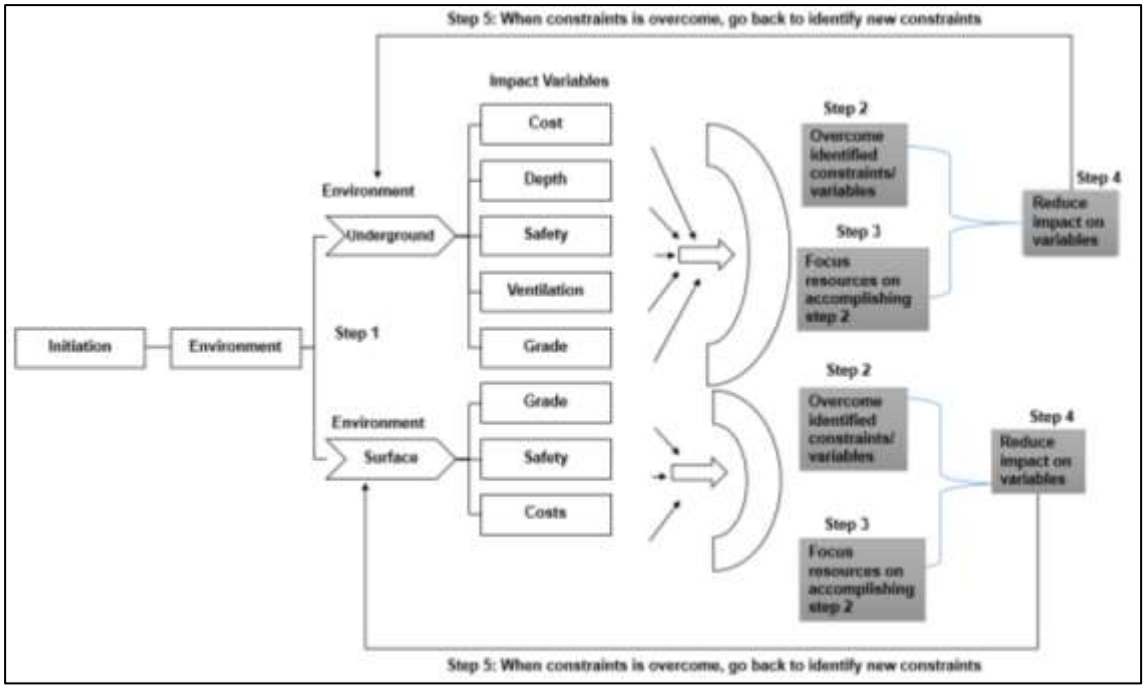


Figure 1: Theory of Constraints tailored model

2.3 Definition of Terms

AI is a pervasive technology, the application and impact of which span all sectors of the economy, from manufacturing and media, to education to healthcare. According to Buchmeister, Palcic and Ojstersek (2019), as adopted from the dictionary, AI is a computer system that is able to perform tasks that generally require human intelligence.

In its simplest form, Cunneen, Mullins and Murphy (2019) adopted AI definition from John McCarthy (1956), who introduced artificial intelligence as the inaugural, conceptual framing of machines, which carry out intelligent tasks. Skrop, Holczinger, Bakon, Mihalics and Jaskó (2018) meanwhile define AI as a collection of problems and methods related to making computers behave intelligently and solve complex problems. AI-based systems are able to perform

specific tasks better than human can. Lottermoser and Barnewold (2020) describe AI as techniques that allow recreating human-like cognitive abilities to automate tasks and processes.

Machine learning is a sub-division of artificial intelligence. Bajic, Cosic, Lazarevic, Sremcev and Rikalovic (2018) define machine learning as a science that combines big data analytics and advanced methods technologies of algorithms and software, which collect and extract data from an environment for purposes of gaining meaningful information and knowledge from the big data (BD). As a results, ML is able to achieve higher level of competency and requirement than a human.

Wuest, Irgens, Klaus-Dieter and Weimer (2016) define ML as allowing computers to solve problems without being specifically programmed to do so (adapted from Samuel 1959). Skrop, Holczinger, Bakon, Mihalics and Jaskó, (2018), indicate that ML uses data driven modelling methods.

Autonomous vehicles (AV) offer the opportunity to harness the benefits of the latest sensory technologies and artificial intelligence (AI) to make driving decisions which mitigate many risks associated with human driving decision (Cunneen, Mullins and Murphy 2019). They further state that as machines, AV also eliminate decisionality problems associated with the human frailties of fatigue, misperception, and intoxication, along with the problematic decisions humans often make in the context of driving. Delgado et al. (2019), describe AT as terrestrial, aerial, or nautical vehicles that can be piloted remotely, or which are autonomous. Lottermoser and Barnewold (2020) define the operation of existing machines and unattended processes without human control. Finally, according to Singh and Arat (2016), AT can be described as vehicles using sensors like camera, radar, and DL for purpose of vehicle control.

2.4 Prior Comparative Industry Studies in AI, ML and AT

Manufacturing including automotive and construction are considered to be comparative industries due to processes and equipment employed. The application of Artificial Intelligence (AI) Autonomous robotics and Machine learning (ML) are active in most of automotive industries.

Bajic et al. (2018) take a theoretical approach to summarising the challenges and future trends of ML applications for smart manufacturing. The study findings shows that the application of ML lead to the achievement of defect-free and fault free processes. In addition, other successes include successful in manufacturing areas such as optimisation, control, troubleshooting, security and verification where the increment of transparency of the entire manufacturing environment is beneficial for cost reduction without affecting quality of production.

There are challenges associated with this technology (Bajic et al. 2018). These includes gathering of the big data from the manufacturing environments in order to have enough extracted knowledge and information for developing the ML algorithms that are able to learn automatically from patterns and previous behaviour. Secondly, the storage space represents another challenging issue, which leads to privacy, security, and economic questions. Lastly, with continued development, skills, and human experts represent another challenging issue.

In another study done in Sweden, Gryth and Runderbug (2018) aimed to provide general insight into the impact of AI on business within the automotive sector. The findings indicated that AI is enabling automotive companies to leverage data about customers, collaboration with partners and with long expectations of impact on strategic decisions and positioning.

In the USA, Wuest, Irgens, Klaus-Dieter and Weimer (2016) conducted a study overview to focus on challenges of manufacturing sector and benefit examples of successful machine learning applications in manufacturing environment. The key findings indicate that manufacturing businesses are seen through the reduced contribution to the GDP in first world countries due to inefficiencies and poor old designs. However, in recent years several initiatives to revamp the manufacturing

sector were started. This were propelled by ML and AI development, which led to terms like Advanced Manufacturing, Factories of the Future, and smart manufacturing. Therefore the conclusion can then be made with confidence, that ML is already a powerful tool for many applications within intelligent manufacturing systems and smart manufacturing and its importance will increase further in the future.

Another study by Skrop, Holczinger, Bakon, Mihalics, & Jaskó (2018) in Hungary focused on highlighting the architecture of the Industry 4 laboratory and the challenges of applying artificial intelligence to industrial processes. Their findings highlighted the next generation of industrial systems, envelopes, as well as many areas and key technologies like big data, smart factories, cyber physical systems, the Internet of Things and interoperability with which the whole supply chain can be digitised. Therefore, a factory is not only fully automated, but all of its machines are interconnected digitally within one system. The physical systems communicate and cooperate both with each other and remotely with human workers. Such a smart factory makes it possible to monitor all the physical processes in real time and make effective decentralised decisions. However there is also challenges associated with the connected ecosystem. This include training, as well as many clean and bias-free data sets. Cybersecurity is another threat that had to take into consideration with the increasing use of connected technologies, which can expose business to risks.

Another study conducted in Luxembourg by Singh and Arat (2016), focused on an overview of advances and in deep learning (DL) techniques in the context of automotive applications. The key findings of the study indicated that with an increase collection of data enabled by connectivity and sensors, DL will play a huge role in building data set for future reiterations which will properly cars for instance to make decisions for fully autonomous vehicles. Virtual sensing for vehicle dynamics application, vehicle inspection and heath monitoring, automated driving and data-driven product development are key areas that are expected to get the most attention.

Looking at construction, a mixed research method was employed combining literature review, qualitative, quantitative data collection and analysis (Akanbi et al., 2019). The purpose of this English study is to assist stakeholders to understand the main industry specific factors limiting the adoption of robotics and automated systems in the construction industry. The findings indicate that use of robotics has the potential to provide numerous advantages to the Construction industry, however the levels of adoption are very low. This is because of various factors, include economic, technical and cultural dynamics and weak business case factors.

In general, the use of AI, ML and autonomous bring about benefits to the businesses however there is also associated challenges. The benefits are similar in different areas and include, cost reductions, efficiencies and increased productivity. Inherent issues include big data storage and cost implication from cyber security.

2.5 Prior Studies on AL, ML and AT in Mining

The mining industry has been sluggish in the implementation of AI, ML and AT technologies. There are also few areas where this AT technologies has been implemented. In SA, studies by Green et al. (2010) and Grobler (2010), demonstrated use of autonomous vehicles for safety and production, respectively. In Australia Reid, Ralston, Dunn and Hargrave (2011) and Kobussen, Agnew and Broadbent (2017) also proved concept with the autonomous vehicles for production. In China Li & Zhan (2018) also demonstrated the application of intelligent autonomous vehicle.

Green et al. (2010) explored the potential for deploying an autonomous robotic to prevent the rock fall incidents by using it to identifying the high-risk areas. The key findings indicated that lives can be saved by using robots to do entry examination before miners start their shifts. Safety is not only a factor, but there is an addition benefit associated with cost and stoppages which will fall away saving mining company’s money and production downtime.

In another study in SA by Grobler (2010), the focus of the study was to discuss the processes involved in developing and implementing the autonomous transportation system. It also described the requirements for such a system and the lessons learnt. The results showed that the AT system was successfully implemented at the mine on a fixed production loop. The success of the loop was based on the established requirement of company needs and forming a partnership with the original equipment supplier (OEM) to ensure success of the project.

A study by Reid, Ralston, Dunn and Hargrave (2011), based in Australia focused their paper on benefit of increasing the overall rate of roadway development with automation capability as well as providing a safer working environment for underground mine personnel based on comprehensive performance evaluations. The results demonstrated that a “self-steering” capability to enable a Continuous Miner to automatically maintain a given mining heading and mining horizon, under which production conditions was achieved. The project outcomes represent an important move towards achieving a step change improvement in underground roadway development practice, while in the process increasing productivity and improving safety.

Another study done in China by Li and Zhan (2018), looked at autonomous intelligent driving by relying on a wireless communication system, location, and navigation system and data acquisition system description. Intelligent autonomous driving mining not only improves the effectiveness of mining equipment and the intelligent monitoring of mining processes, but also significantly improves mining efficiency, thereby reducing the mining cost and improving the competitive ability of mining enterprises. At the same time, intelligent mining can reduce the number of field operators and the risk of accidents especially with impact on personnel.

In Australia, a study by Bassan and Knights (2011) was done to focus on how advanced analytics techniques can be applied to the fundamental challenges faced by the mining industry. The findings indicated that advanced analytical capabilities will be one of the key enablers of network centric operations, which will transform the mining industry. Network centric operations will be typified by

increased levels of business process integration and greater automation throughout the value chain.

In another study from Brazil, Sganzerla, Seixas and Conti (2016) focused on unlocking value associated with digital transformation in mining. The evidence of combination of market volatility, changing global demand, radically different input economics, new locations in search of more reserves, a focus on a longer asset lifecycle and a commitment to operational excellence including policy shifts around the globe with decades of cost reduction and the aging workforce have left mining companies with limited resources. Based on this facts, industry was pushed towards a seismic shift to digital transformation. However, the mining companies are not fully taking advantages of this development albeit obvious benefits.

A study conducted in Germany by Lottermoser and Barnewold (2020) used insight reports of leading consultancy agencies by employing co-word analyses and text-mining techniques to establish an overview of digital technologies relevant to mining companies as presented and discussed by mining journals and the media. The key findings indicate that analysis of 158 active surface and underground mines indicated limited uptake of implementation of digital technologies and also that there is still obstacles in the adoption of digital technologies in mining.

However, there are several mine sites that demonstrate successful and economically viable implementation of digital technologies. For example, in 2014, the Éléonore Gold Mine in Canada installed an IoT system monitoring system, which reduced the energy cost by more than $2 million per year. Another example is the investment into autonomous trucks at an open-pit mine in Western Australia. The mining operation benefited from this digital transformation. Thus, there are already several business cases in the mining sector that highlight the benefits of investing into digital technologies.

In the USA (2019), a study was conducted to analyse the impact of AI, ML, AT, and robotics, and their effect on the future of work and humanity including expected benefit. The key findings concluded that AI has many benefits in various

areas including military, health, manufacturing and factory automation, finance, hazardous environment and many others. The benefit comes with other unintended risk and ethics to society. These include potential to replace humans and also cognitive ability, which will surpass that of humans at some stage.

In Australia, a study by Duin, Meers and Gibson (2007), looked at the changing trends in mining practice, analysing available technology as well as currently emerging research into automation and further discusses the need to integrate machinery and processes in order to see increases in productivity and safety. The findings found that in many instances, there was high variability in mining conditions for the same processes. Therefore the different variables will contribute differently to the success of automation in different mines due to a lack of integration. The integrated automated system have been proven to work in civil industries in the process, eliminating manual operations out of the cycle to make it safer.

In Ukraine Zelinska (2020), the study examined technologies and potential application of machine learning at mining companies. The findings indicated the possibilities of applying machine learning algorithms for purposes of enhancing efficiency in the mines.

In the USA, a literature review of current applications of AI, ML, AT and robotics was conducted by Hyder and Siaun (2018). The purpose of the study was to establish areas of opportunities in application of current status of AI, ML and AT technologies implementation in the mining industry including challenges resulting from these technologies and potential strategies to overcome these challenges. The technologies have the potential to bring a new revolution into mining industry by reducing cost, improving productivity and efficiency of operations, and by decrease the environmental footprint of mining through the use of intelligent systems.

The study further made assertions the technologies are still in infancy with limited data in the industry, *where there is a need to explore this further though qualitative approaches to assess how this implementation is received by different*

stakeholders in the industry and what their perceptions are about the threats, challenges, benefits, and potential impacts.

2.5.1 Proposition 1

Use of AI, ML and AT will have positive impact on mine production and people. Based on the prior studies, AI, ML and AT manufacturing, including automotive and construction are considered to be comparative industries due to processes and equipment employed, respectively. The application of Artificial Intelligence (AI) Autonomous robotics and Machine learning (ML) are active in most of automotive industries and there is benefits of efficiencies.

In mining, a study Li and Zhan (2018), asserts that Intelligent autonomous driving mining not only improves the effectiveness of mining equipment and the intelligent monitoring of mining processes, but also significantly improves mining efficiency, thus reducing the mining cost and improving the competitive ability of mining enterprises. At the same time, intelligent mining can reduce the number of field operators and the risk of accidents especially with impact on personnel.

2.5.2 Propositions 2

Implementing AI, Ml and AT technologies will have to overcome inherent challenges and hurdles to realise the benefits. The analysis of 158 active surface and underground mines indicated limited uptake of implementation of digital technologies and also that there is still obstacles in the adoption of digital technologies in mining (Lottermoser and Barnewold, 2020). With the benefit associated with the AI, ML and AT, it is interesting that there is limited uptake of this technologies. It is important to mining companies to overcome challenges affecting implementation of inherent challenges to realise competitive benefits which includes safety, efficiencies, and productivity in the process also attract necessary investments.

2.5.3 Proposition 3

Strategy decisions will drive sustainability and secure future of SA mining industry using AI, ML and AT

The AI, ML and AT have the potential to bring about a new revolution into mining industry by reducing cost, improving productivity and efficiency of operations, and by decreasing environmental footprint of mining through use of intelligent systems, according to Hyder and Siaun (2018). It is essential for the industry to make long-term decisions, which will then have lasting impact in the industry for its long-term sustainability.

2.6 Summary and Concluding Remarks

The definitions of AI, ML and AT consistently confirms a common structure that highly skilled people drive the front loading of this technologies, but the resulting applications is that the tasks will ultimately be achieved by computers and or machines with computers in the process replacing humans. Therefore, AI as defined by Buchmeister, Palcic and Ojstersek, (2019); Skrop, Holczinger, Bakon, Mihalics, and Jaskó, (2018) and Lottermoser and Barnewold (2020) all show that computers performs tasks that generally require human intelligence, machines carry out intelligent tasks, behave intelligently and solve complex problems, and predict the future systems outputs from known input values. The characteristics of AI can be seen in ML and AT which are both subset of AI.

It is expected that these technologies would be able to contribute immensely to mining operations, where machines will be able to make decisions normally made by people. Issues of safety, cost reduction, and efficiencies are attributable to these technologies. Therefore, the question as to whether to explore further is where these technologies will be suitable in the mining industry. The fact that technologies advocate for machine intelligence and impact on employment will become an issue in the mining industry.

According to Hyder and Siaun (2018), Implementation of AI, ML, and AT in the mining industry started about a decade ago, with the first application of

autonomous trucks. Autonomous technologies provide many economic benefits to the mining industry through cost reduction, productivity improvement, reduction in exposure of workers to hazardous conditions, continuous production, and improved safety.

The technologies are also expected to contribute to strategic decision and different business models. Studies by Reid et al. (2011), Green et al. (2010) and Bajic et al. (2018) confirm this assertion. There is also evidence of impact on other industries, where according to Siau (2019), the study indicated that AI has many benefits in the various areas including military, health, manufacturing and factory automation, finance, hazardous environment, and many others. Grobler (2010) A study confirmed that here in South Africa, autonomous vehicles were successfully implemented in a production loop in an underground mine.

However, Sganzerla, Seixas, and Conti (2016) indicated that mining companies are not fully taking advantages of this development, albeit harbouring obvious benefits. Lars Barnewold and Bernd Lottermoser (2020) established that 158 active surface and underground mines indicated poor and limited uptake of implementation of digital technologies. Also Delgado et al. (2019) found that robotics has the potential to provide numerous advantages to the construction industry, but that the levels of adoption are very low.

There are also challenges associated with these technologies, according to Bajic et al. (2018). These includes gathering of the big data from the manufacturing environments. Storage space represents another challenging issue, which leads to privacy, security, and economic questions.

The preliminary literature study indicates that there is some notable success in application of AL, ML and AT, especially in other industries. However some of the key findings indicate reluctance of adaptation of these technologies in the mining industry.

Based on the literature study, there are areas that require further exploration, which include specific uses of this technologies, the impact of implementation, what motivation is there for implementation of autonomous technology, and

finally, the impact on people (employment opportunities, worker relations and workforce demographics) in SA.

2.6.1 Propositions 1

Based on the prior studies, AI, ML and AT will have impact on processes on production and people.

2.6.2 Propositions 2

Implementing AI, ML and AT will have to overcome inherent challenges and hurdles to realise the benefits.

2.6.3 Propositions 3

Strategy decisions will drive sustainability and secure future of SA mining industry by using AI, ML and AT.

CHAPTER 3. RESEARCH METHODOLOGY

The purpose of this section is to highlight the methodological approach taken for the research process which include methods for collecting and analysing data. The chapter covers research design, research method, data collection methods, population and sample, the research instrument, procedure for data collection, data analysis and interpretation, limitations of the study, validity and reliability, and ethical considerations.

3.1 Research Design

Research design is a comprehensive plan for data collections in a research project (Bhattacherjee, 2012). According to Hofstee (2011), the research design section involves the overall approach to testing the research question or statement being discussed. The topology of the research design can be classified into two categories, namely, empirical studies and non-empirical studies (Mounton, 2013). Empirical studies derive new knowledge from data, whereas, non-empirical studies use the literature review, modelling and the philosophical and conceptual analysis to develop new knowledge. This study will be an empirical study because this design allows for the researcher to derive in-depth data about the research problem.

3.2 Research Method

Research studies can utilise a quantitative, qualitative and or a mixed research method that is both quantitative and qualitative (Bhattacherjee, 2012). The qualitative research method usually has no measurements or statistics but uses words, descriptions and quotes to explore meaning, and quantitative usually contains numbers, proportions and statistics (Williams, 2007). For the purposes of this study, the empirical qualitative technique will be adopted, where the researcher seeks to gain a deeper insight into the phenomena.

3.3 Population and Sample

Polit and Hungler (1999) refer to the population as a totality of all objects, subjects or members that conform to a set of specifications. In this study, the population will be representatives of organisations in South Africa.

Sampling refers to the selection of a subset of persons or things from a larger population, also known as a sampling frame (Scott & Morrison, 2007). In this study, the sample will be pulled from mining professionals and industry executives. For the purpose of this study, a target sample size of between 12 - 15 respondents was found to be adequate in line with a qualitative study approach. A total of 14 respondents were interviewed. The respondents were selected based on their level of experience and seniority within the respective organisation. Mines selected have similar characteristics, which created a pool of 5 categories of mines each class representing one mine. The sampling methods will be convenient with purposive sampling and will allow for snowballing effect to ensure further referrals from respondents.

3.4 The Research Instrument

The study instrument **(Appendix A)** is interviews conducted on Microsoft teams and Google meet platforms. The logic for the platforms was as a result of the Covid-19 pandemic and its associated restrictions, which precluded face-to-face interviews. This proved to be ideal as the respondents were spread throughout the country in at least five provinces, which included the North West, Limpopo, the Northern Cape, Mpumalanga and the Free State. The research instruments was administered by use of questionnaire which is attached in Annexure A. The interview question list was prepared but allowed for additional clarity whenever is required. In order to drive value and insights from respondents, interviews structure was explained in advance and necessary guidance was provided when required to ensure proper contextualisation of responses relevant to the questions.

3.5 Data Collection Method and Procedure

The primary data collections method anticipated for this study will be interviews **(Appendix D)** with identified respondents. The process will be methodical with consideration given to the identified respondents for purposes of introductions and their participation.

A formal request and interview schedule will be set up in advance, with necessary preparation on the part of the respondents with some guideline for the interview direction. This is done so as to ensure alignment to the study. The interviews will be set for a period of at least 60 minutes. It is anticipated that each participant will be requested to assist with further referrals of relevant candidate for interviews based on their experience.

3.6 Data Analysis and Interpretation

Data analysis will be conducted by employing the thematic analysis process. Through its theoretical freedom, thematic analysis provides a flexible and useful research tool, which can potentially provide a rich and detailed, yet complex account of data (Braun and Clarke 2006). The process follows six steps, starting with familiarity with the data, generation of initial codes, identification of themes, reviewing of themes, definition of themes, and finally, the writing of the report.

3.7 Limitations of the Study

Potential limitation exist due to Covid-19, which will affect the mode of one-on-one interviews. The limited data in the field and lack of immediately available shelf equipment might contribute to poor information gathering. In the absence of obvious evidence in the sector, negative bias might exist from the respondent casting aspersions that this technologies due do not work.

3.8 Transferability, Credibility and Dependability

The process of data collection was homogeneous throughout the study whereby an interview guide was used to create consistency in the data collection method. It is noted that no single interpretation method exists for qualitative data but it is expected that the data analysis process will ensure transferability of this study. To ensure the credibility of the interview questions, some of the questions were extracted from published studies; while the rest were tested with the academic supervisor for their validity.

Dependability of the study is anchored in the intense application of thematic analysis process as indicated in section 4.4 of this document. These steps could be applied by subsequent researchers in their attempt to recreate this study. These however will dependent largely on the prevailing conditions at that specific point in time which might influence resultant replication of the study.

3.9 Ethical Considerations

Ethical certification **(Appendix C)** was applied for and granted to ensuring credibility, credence to study, ensuring absolute confidentiality to respondents and demonstrating professional conduct in the process ensuring that knowledge is captured in best suitable way taking cognisance of factors that can potentially jeopardise the study and integrity of the study. Therefore the following will be upheld in line with Ethics and protocols as dictated by Wits Business School (WBS):

- The purpose of the study was explained to all the respondents and concern form was extended for necessary signatures **(APPENDIX B).**
- The name of the organisation and respondents will not be included in the final reports
- A plagiarism declaration form will be signed and the study will be subjected to Turnitini for plagiarism analysis to ensure absolute compliance to University standards

3.10 Conclusions

To ensure credibility of the study, a research methodology and design was completed to ensure that desirable results is achieved. As a result, this chapter covered detailed design, which includes research method, data collection methods, population and sample, the research instrument, procedure for data collection, data analysis and interpretation, limitations of the study, validity and reliability, and ethical considerations. Ethics is particularly important so as to ensure necessary confidentiality in line with university protocols that organisation and individuals are not compromised in the process.

CHAPTER 4. PRESENTATION OF FINDINGS

4.1 Introduction

This chapter presents the findings of the study, based on use of AI, ML and AT in the mining industry, using quantitative research methodology. The background of the mines and respondents are outlined. A thematic process flow was utilised as described briefly in 3.6 and also detailed in section 4.4. Therefore, the chapter consists of the mines and locations, respondents' background, and a thematic process, which was followed for data interpretation. The interpretation and results are viewed though associated prepositions. Finally, conclusions are made.

4.2 Background Information

4.2.1 Respondents Mines

For the purposes of study, five classes of mines were grouped based on characteristics which are considered similar, which then represent a mine. The groupings characteristics is mostly by nature of the ore bodies, equipment uses, typical mining methods, whether surface or underground. Although there might be many variations of mining methods for both surface and underground, the selected classes' characteristics pertaining to application of AI, ML, AT are considered to be similar, such that it will not be necessary to consider each variation. Therefore, surface mines in this case are classed together but for underground environment, is further divided by those that are narrow in nature, with conventional mining methods, those that use trackless equipment on a board and pillar mining setting, those that exist in massive reef settings, and lastly those that exist in massive block caving (refer to Table 1). Geographically the five mines (classes) mines for the study are located in the following provinces of Mpumalanga, Gauteng, North West and Limpopo. The representivity by location

is shown Figure 2 below. These provinces are well known for their mining activities in South Africa.

Table 1: Mine Classes

Mine Type	Mine Method	Typical Equipment	Technology	Classification Of mines
Surface - Coal	Open Pit	Trucks, Loaders, shovels, excavators	Mechanised mining process	1
Surface - Iron	Open Pit			
Underground - PGMs	Board and Pillar	Trackless drill rigs and Loaders	Mechanised mining process	2
Underground - Block cave	Massive Block Cave	Trackless drill rigs and Loaders	Mechanised mining process	3
Underground - Gold	Massive Reef	Trackless drill rigs and Loaders	Mechanised mining process	4
Underground - Gold and PGMs	Narrow Tabular Reef or Conventional	Winches and scrapers, Hand held rock drills and Locos	Considered to be mostly primitive and Labour intensive	5

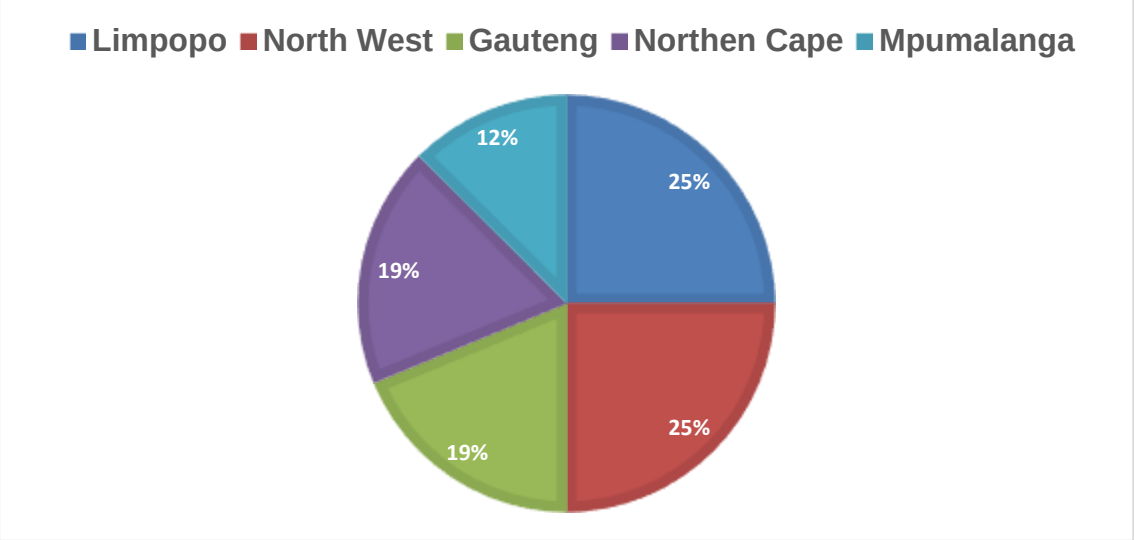


Figure 2: Location of Mines and representivity

The sample distribution of the mines is based on 65% for underground and 35% to surface mining operations, as indicated in Figure 3.

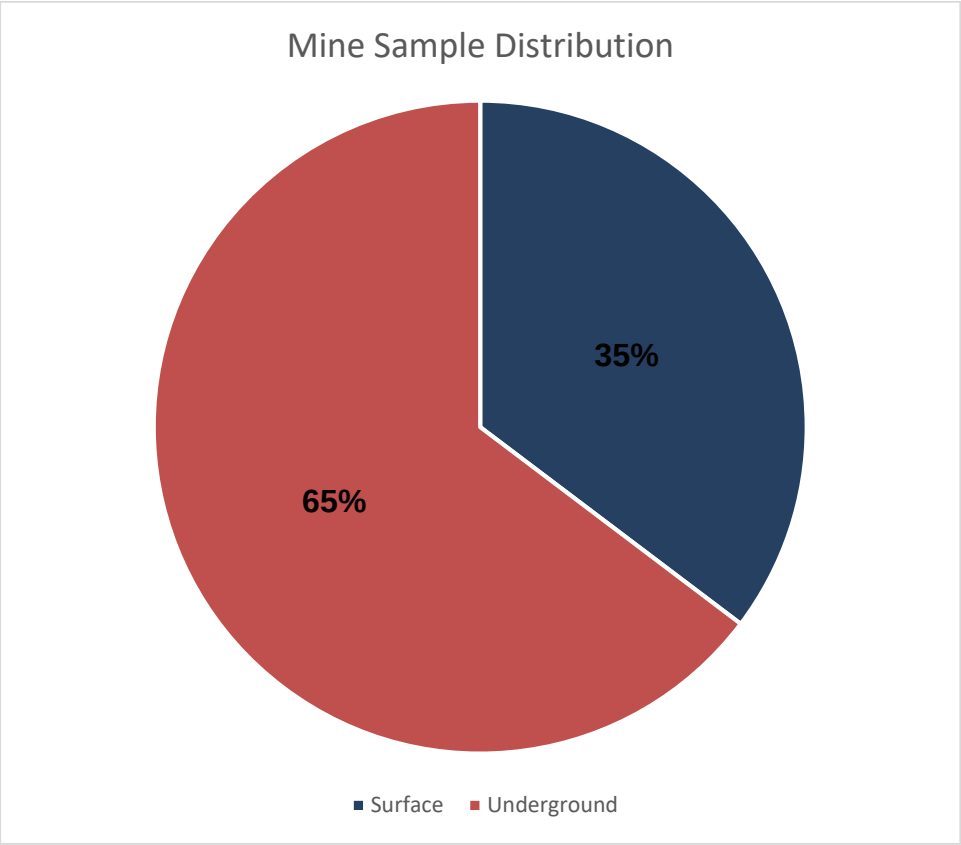


Figure 3: Mine sample distribution

4.2.2 Respondents background

A total of fourteen respondents were interviewed online using Microsoft Teams and Google Meets. The advent of Covid 19 pandemic has channelled all interviews to be executed online without the benefit of contact. Marsview was used for transcription of audio file to Word. Other tools included Microsoft Word and Xcel for analysis and presentation of the data. The programme has limitations due to biases in accent and pronunciation driven by original country of development. However, this was mostly improved by repeating audio passages to capture factual statements, where this was found to be lacking.

In line with ethics and confidentiality on respondents and companies, no names would be utilised for the purposes of this study. All the respondents are senior managers and executives in their operations with a total combined experience of more than 250 years. The average experience of each respondent is shown in

Figure 4. The years of experience indicate established repository of knowledge amongst the respondents.

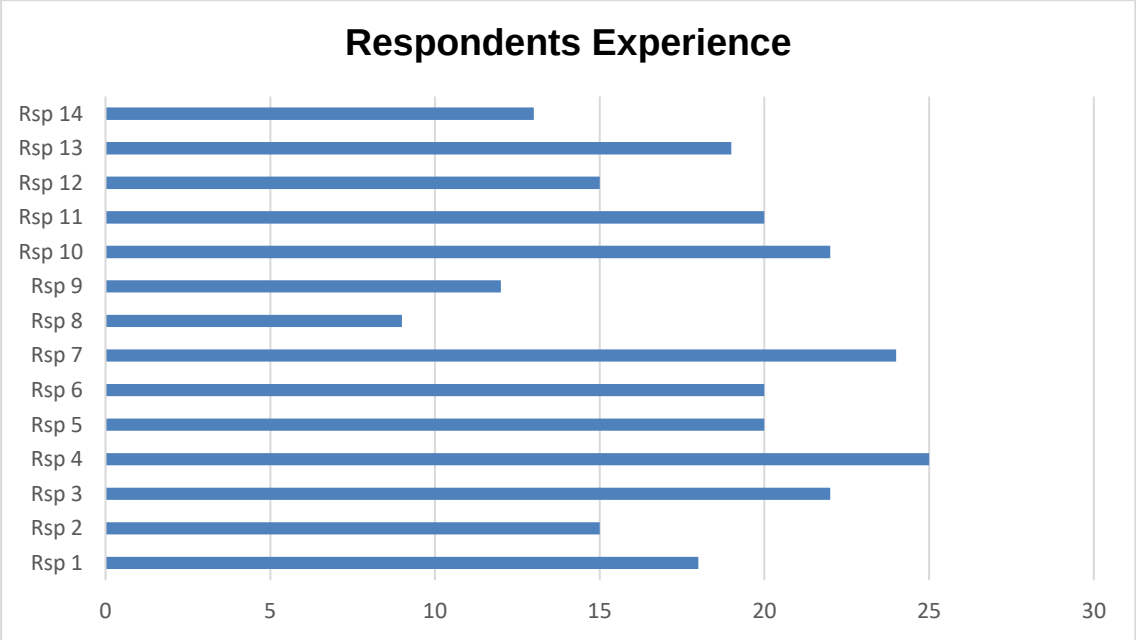


Figure 4: Respondents Years of Experience

The respondents occupies varies positions in their operation as shown in Table 2 below. The positions are generally in executive levels. Their work responsibilities in the organisation covers operations, mine technical services, technology, business improvement, and projects for driving various improvement technologies on the mines. The age group categories of responded is between a range of 30-40 and 40-50 years compromising of 12 males and two females, with majority being of African descent. Age factor was used as part of the instrument to ensure that respondents have adequate experience. The gender representivity does not have a bearing on the outcome of the study as all respondents are deemed competent in their respective positions at the workplaces. All respondents will have insights of application of AI, ML and AT in their workplaces, which the study seek to evaluate.

Table 2: Respondents Information

Code 1	Gender	Race	Experience	Department	Job Level
Resp 1	Male	African	18	Business Unit	Executive
Resp 2	Male	African	15	Technical Services	Senior Manager
Resp 3	Male	African	22	Business Unit	Executive
Resp 4	Male	African	25	Technical Services	Executive
Resp 5	Male	African	20	Technical Services - Projects	Executive
Resp 6	Male	African	20	Business Unit	Executive
Resp 7	Male	African	24	Technical Services -Engineering	Executive
Resp 8	Female	African	9	Operations	Mid Level Management
Resp 9	Male	White	12	Technical	Executive
Resp 10	Male	African	22	Business Units	Executive
Resp 11	Male	White	20	Technical Services-Technology and Innovation	Executive
Resp 12	Male	White	15	Technical Services -Technology	Senior Manager
Resp 13	Male	African	19	Operations	Site Management
Resp 14	Female	African	13	Technical Services	Senior Manager

At least 31% of the respondents report directly to the Chief Executive Officer (CEO). The next 25% of respondents are sitting two and three levels below CEO, respectively. The last 19% respondents were four reporting levels below the CEO. All of the respondents form part of the executive in their respective operations.

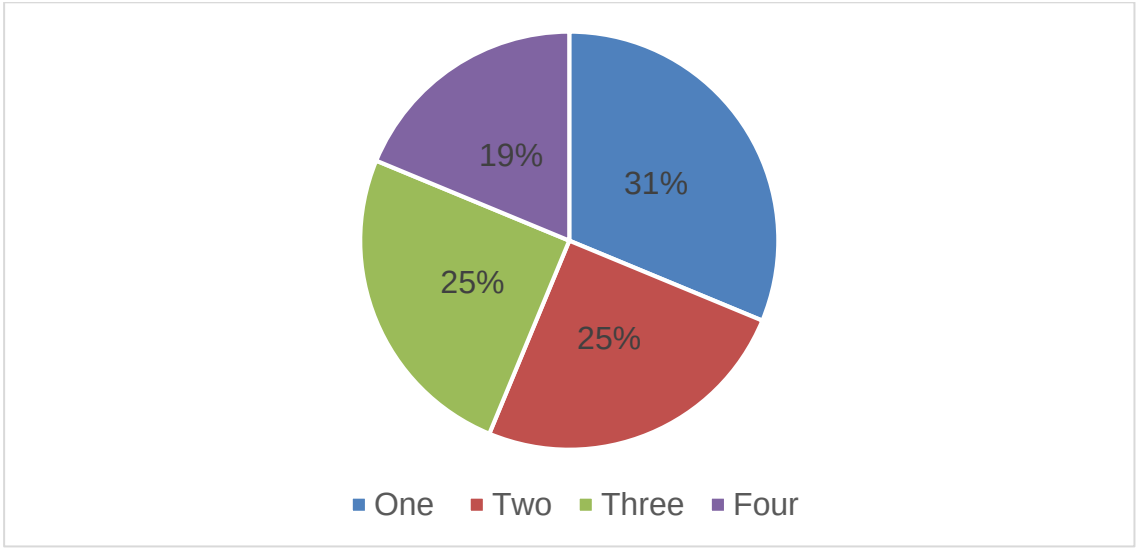


Figure 6: Reporting Levels to CEO

All respondents are qualified not only with experience, but with the requisite qualification for the positions they occupy. More than 60% of have a university degree and at least three respondents have master of management level and a Master of Science degrees. Figure 6 indicate the breakdown of all respondents' qualifications.

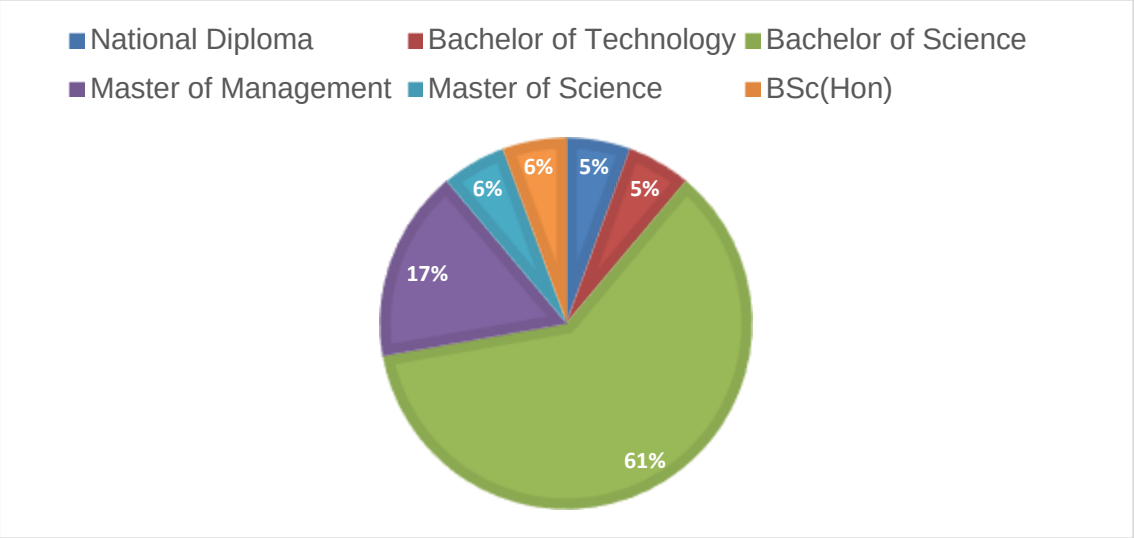


Figure 7: Respondents Qualifications

4.3 Research Questions

The research questions are designed to establish implication of AI, ML and AT in SA mines and are is also intended to solicit how implementation of this technologies are perceived by industry stakeholders. The questions will further gauge and solicit respondent's views on practical observations, impressions, and forward-looking suggestions. The instrument intention is also delve deeper into perceived threats, challenges, benefits, and potential impact areas in various value chain of the mines.

Therefore, the question are as follows:

- What are the long-term strategic decisions being made in support of AI, ML and AT?
- How do the implementation of these technologies affect the workforce demographics, worker relations and availability of jobs?
- What are main hurdles and challenges in implementing these technologies?
- What are the potential uses of AI, ML and AT in mining industry?
- What are major impacts areas of implementing these technologies?
- What are the long term strategic decisions being made in support of AI, ML and AT?

4.4 Thematic Analysis Approach

Thematic analysis (TA) approach follows a six-step process as indicated in Figure 8 below. According to Braun and Clarke (2006) note that TA through its theoretical freedom, provides a flexible and useful research tool, which can potentially provide a rich and detailed, yet complex account of data. The initial step requires familiarity with the data and then process goes sequential Initial coding, themes, review, definitions and finally the report.

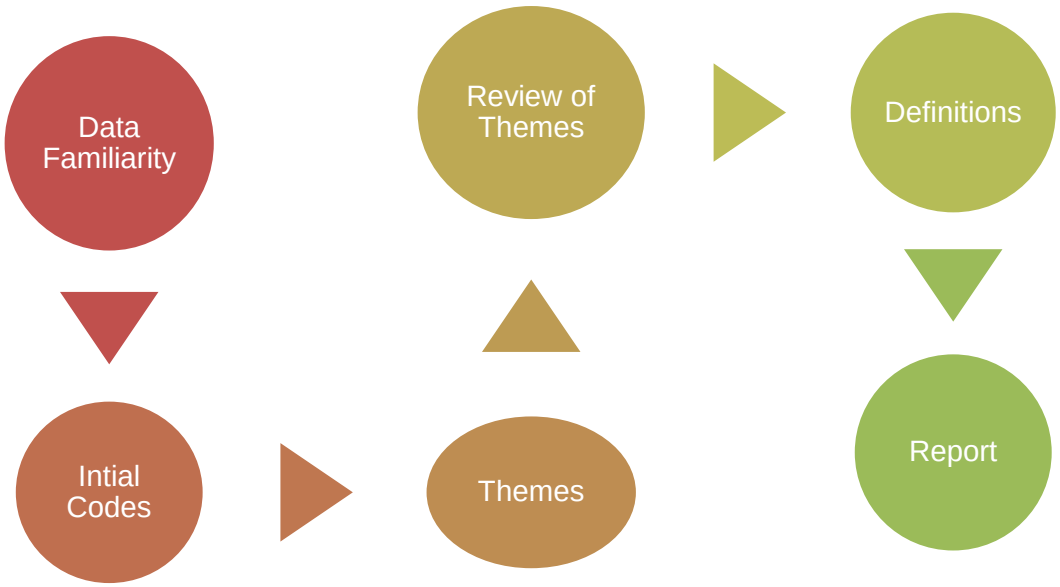


Figure 8: Thematic Process

4.4.1 Data Familiarity

Initial Impression: What are the potential uses of AI, ML and autonomous technologies in the mining industry?

For the purposes of this study, the industry recognise technology in a number of broader terms associated with mining methods and its associated extraction technologies. For ease of reference, the type of mining methods were grouped in

Table 1 above with associated technologies. For the purpose of this study mostly AI, ML and AT will be referred as advanced technology and or AI, ML and AT.

Type **1 to 4** are general more advanced to utilisation of mechanised equipment. Type E is labour intensive, and tasks are achieved mostly by very limited use of equipment, which requires human strength. These mines and types require a different approach, due to the vast differences of constraints and intervention.

Type **1** mining methods which are on surface are mostly at an advantage. The operating environment is conducive and exposed to general enabling infrastructure, which allows for connectivity. There is established core and expansive network of communications (CN), operational technology (OT), and information technology (IT).

It is much easier to access communication towers, satellite, and cables, which constitute a backbone of enabling environment for use of AI, ML and AT. Most of IT devices are readily available and can be utilised with easy in the operations.

Therefore it is not surprising that there is more activity in Type 1 operations due to reasons indicated above. Some of time Type 1 mines are considering use of AI, ML and AT. Remote-controlled rock drilling, data analytics at the processing, training, procurement, and drone. All these technologies are subset of AI, which drive AT and MT. There is an opportunity for full automation in the processing plant and production environment where drilling and blasting, loading, ore transport are tasks, which are repetitive. Due to local variability in the ore which impact on plant efficiencies, use of ML could play an impactful role in increasing optimised processes.

Type **2** to **4** are underground mines, ore bodies could be large in width and use mechanisation process, where trackless equipment is utilised for production. Being an underground operation requires an effort to ensure connectivity. There is no immediate benefit of CN, OT and IT, which requires initial investment to bring underground. There is an added layer of complexity as mining is a dynamic process and robust devices are required to support AI, ML and AT. Rocks are

continually excavated creating a network of advancing and continuous tunnels. However, there are potential uses of the AI, ML and AT with appropriate investment to allow for autonomy in production cycles and for and utility on demand services.

Type **5** mining methods has similar characteristic as type 1 to 4, but with an added layer of complexity, driven by the nature of the ore bodies, which are thin in nature which complicate extraction process. The process is labour intensive and ore extraction excavations are smaller as well. Therefore, the equipment is handheld, small, and used by people in confined spaces. There is an opportunity and reorientation of the process so as to ensure that benefits associated with AI, ML and AT are realised.

Initial Impression: What are some major impacts areas of implementing these technologies?

It is notable that there is huge potential for use of AI, ML and AT in the mining industry. It is the impression of the researcher that all respondents agree with this fact there the scope is vast. However, each area, business unit, and its influence of control must find its specific constrain for intervention to seek impact solutions. There is potential impact areas for ease of use of these technologies, but there is a challenge regarding progress and implementation at this stage. The impact areas include achieving safety and health of employees, access to dangerous areas, access to deep ore bodies, mining of pillars, and mining of un-pay ground due to increased efficiencies (Increase in mineable resources), process efficiencies, addressing the people-skills deficit, mine planning and exploration, and ore transport and logistics. Utility management services and including on demand service allocations. Change in operating philosophy took place due to response to challenges brought by safety, inherent inefficiencies in the system, production (mine and process plant), and pandemics like Covid 19.

Initial Impression: What are main hurdles and challenges in implementing these technologies?

Issues of safety is exacerbated by mostly its high-labour intensity concentration in workplaces, especially in the narrow reef conventional mines. The process and production inefficiencies are as a result of variability in extraction, ore body complexities, and dynamic of processes. The opportunity of predictive maintenance is especially attractive as it will contribute to efficiencies and limit production loss with advance knowledge of failures and timeous procurement of required parts.

Initial Impression: How do the implementation of these technologies affect the workforce demographics, worker relations and availability of jobs?

There is general belief amongst the respondents that workforce demographics will improve due to strength being replaced with cognitive ability. Representation of women and disabled persons will become possible, even increase. However, there are two divergent narratives that women in particular are less attracted to technical work in the mines, and that, due to experienced high pool of males, there is a lower female count due historical legacies. This will take time to change. There is an acceptance that the representation of women will increase although at a slower pace. A more professional outfit created by skilled labour will lead to a more improved work relations. Job loss is a reality, but there will be concerted effort to retain jobs through upskilling and reconfiguring how work is done with assistance of technology through digitisation process. However, where job losses are inevitable community development and creating pools of skills, which support AI, ML and AT. It is preferable that Government play an integral role to stimulate secondary sectors like agriculture so as to ensure employment.

Initial Impression: What are the long term strategic decisions being made in support of AI, ML and AT?

The realisation of benefit as driven by specific constrain is encouraging however concerted effort is required between the sector, its suppliers, and government.

Leadership is crucial as in driven by Chief Executive Officers (CEO) and driven by the country's president as the sector is considered strategic. Where impact on job losses cannot be avoided, a concerted effort is required. A collaborative approach is also required to ensure a culture of digitalisation, enabled environment, research and investment is required to ensure success.

Initial Impression: How do you see the AI, ML and AT technologies changing the future of mining organisations in South Africa?

The use of 4IR technology will change the future fortunes of the industry ensuring long life of mine, lead to safer, smarter and more efficient operations. In terms of people, diversified, skilled and remuneration will prevail. Impact on health will be drastically minimised. In the absent of on-shelf equipment and support of technology, hostile environment and capital investment this will remain a far distant reality. It is, however, encouraging that there are activities in the industry in the direction of this technology, albeit with bigger companies, have the most advantage due to a bigger purse. Some of the technologies that came about as a result of frequency and severity of accidents is the AI driven detection of persons and vehicles in proximity. This was driven by Department of Mineral Resources (DMR) through statutory enforcement.

4.4.2 Generations of code

Generation of code is an elaborate process derived from the respondent's interviews and transcripts. It involves tagging and forming qualitative data, which is done to establish codes and emerging themes. The technique provides a process of analysing the data with various categories of codes of similar views which are grouped together to establish a pattern. The initial codes generated are indicated in Table 3 (codes and categories). The grouping of codes into categories and themes are then linked to each research question indicated in Table 4 to Table 9.

Table 3: Codes and Categories

Technology	Impact Area	Drivers and Benefit	Risk	Challenges	Opportunities
AI, ML, AT, Big Data	Dangerous areas	Better business insight	Job losses	Affordability is a problem	Automating production
Anti collision system	Underground and Deep sections	Better Quality of decisions	Bias	Bigger companies has capital to invest	Automating processing
Radar monitoring system	Production cycle	Business sustainability	Cybersecurity	Breakdowns	Engineering services
Person Locator	Energy efficiency	Consistency	Difficult to implement	Complexity	Design desired future
Predictive Maintenance	Leadership	Cost	Poor 4ir understanding	Country is lagging behind	Reskilling and avoid retrenchment
Collision avoidance system	Logistics and ore transport	Dangerous can be mined	Too much data	Development of skills	Unlock resources
Vehicle detection system (VDS)	Management of services-water, air ext.	Data analytics	Accountability	Ethical issues, High level of unemployment	Local Manufacturing
Pedestrian detection systems(PDS)	How people work	Drive competitive advantage	Loss of experience	Fear of technology	Increased diversity at work place
Mechanised Mining	Optimisation initiatives	Efficiencies	Changing environment	Global competition	Attract investment
Advanced analytics	Ore transport	Equipment Availability	**Mining Method**	Hostile environment	Improve on Safety including fatalities
4IR	Mine Survey	Equipment Utilisation	Board and Pillar	Infrastructure	Continuous non stop operations
Sensors	Ore passes	Extension of life of mine	Trackless	Labour cost is high	Better jobs and remuneration
Drones	People	Improved remuneration	Surface	Leadership not supportive	Logistics and ore transport
Risk	Engineering and maintenance	Less union activity	Narrow tabular	Legal Complications	Utility management
Sustainability	Processing	Management of procurement	Tabular mine	Limited success	Mine dangerous areas
Industry collaboration with suppliers	People and equipment tracking	Predictive Maintain ace	Narrow reef	Loss of employment	Mine risk analysis
Investment in technology	Mine planning	Productivity	Room and pillar	Mining variability	New mines development
Training	**Education and training**	Profitability	Mechanised	Narrow tabular is a challenge	Modernisation of current systems
Education	Continuous engagement	Real time data	Conventional	No immediate value	Digitalisation of mine process
Community development	Consultation	Remote view of operation	**Workplace diversity**	No shelf equipment	**Long term strategies**
Respond with technology	Meaningful jobs	Resource increased by depth	No physical strength required	No skills	Leadership
Competitive	Train and develop skills	Safety	Technology Levels playing field	Obsolete quickly in changing environment	CEO
Working technology	Economic impacts	Smart Working	More women	Old infrastructure of mines	Country President
Respond to requirement	Community based business development	Waste prevention	Disabled people	Old technology in narrow reef	Digital First organisation
Reskilling in other industry	Skills transfer initiatives	Workplace diversity		Physical environment limitations	Digital approach
Stimulate other industries	Cadet skills programs	**Future**		Poor political will	Culture
Visionary leadership	Unions not against technology	Safety		Poor priority on intervention	adoption
Introduce technology in a responsible way	Workplace improvement	More resources		Poor process efficiencies	enabled environment
Government must be involveld	Inclusivity	Change perception of mining		Project longevity and life of mine	Leadership
Application	Empower Local communities in 4IR	Better and safe mining condition		Resistance and sabotage	Research and investment
AI - Training, production cycle and processing plant	**People**	Mining in air-conditioned room		Robots are still a far development	Collaborate with suppliers
predictive maintenance, real live feed,	Loss off jobs	Effort replaced by cognitive ability		Robust equipment required	
remote mine monitoring, drones, security	Fear of technology	ential to increase women in industry		Safety issues including Fatalities	
flooded mines, seismicity monitoring	Reskilling	Highly skilled		Small companies does not have capital	
Production process, exploration, ventilation on demand	Develop for other industries like agriculture	Increase users		Underground and deep level mining	
ML -Flooded mine, data analytics, mine processes	Create skills for 4IR in communities	Business case must be met			
Utility management, Automation, mine planning,	Safer with 4IR technologies	Partnership with OEM			
Drones, Consumables management, reporting	Government to be involved	Improve productivity			
Big data, process insights, data management,	support and develop other industries	Remote management			
Support derivation of quality decisions,	Curriculum need to be changed to respond	School curriculum development			
AT - Ore transport and logistics, processing		Remote mining			
		Government play a role			
		Activate other industries			

Table 4: Research Question 1

Research Questions	Emerging Themes	Category	Codes
What are the potential uses of AI, ML and AT in mining industry?	Strategy	Application	**AI** - Training, production cycle and processing plant
			predictive maintenance, real live feed, Utility services
			remote mine monitoring, drones, security
			flooded mines, seismicity monitoring
			Production process, exploration, ventilation on demand
			ML -Flooded mine, data analytics, mine processes
			Utility management, Automation, mine planning,
			Drones, Consumables management, reporting
			Big data, process insights, data management,
			Support derivation of quality decisions,
			AT - Ore transport, logistics and processing
	Sustainability	Benefits	Predictive Maintenance
			Productivity
			Profitability
			Real time data
			Remote view of operation
			Resource increased by depth
			Safety
			Smart Working
			Waste prevention
			Workplace diversity
	Strategy	Technology	AI, ML, Big Data , AT, 4IR, Drones, Sensors
			Anti collision system
			Radar monitoring system
			Person Locator
			Predictive Maintenance
			Collision avoidance system
			Vehicle detection system
			Pedestrian detection system
			Mechanised Mining
			Advanced analytics

Table 5: Research Question 2

Research Questions	Emerging Themes	Category	Codes
What are major impacts areas of implementing these technologies?	Sustainability	Impact	Dangerous areas
			Underground and Deep mining sections
			Production cycle surface and underground
			Energy efficiency
			Logistics and ore transport
			Management of services-water, air ext.
			How people work
			Optimisation initiatives
			Engineering and maintenance
			Processing
			People and equipment tracking
			Mine planning
	Skills Development	Education and Training	Training and development of skills
			Community based business development
			Skills transfer and reskilling
			Cadet skills programs
			Workplace improvement
			Curriculum and Academic development to support 4IR
			Empower Local communities in 4IR
			Develop for other industries like agriculture
	Limiting Factor	People	Loss off jobs
			Fear of technology
			Fear of Change
			Sabotage new technology
	Strategy	Drivers and Benefits	Safety
			Better business insight
			Better Quality of decisions
			Business sustainability
			Drive competitive advantage
			Equipment Availability
			Equipment Utilisation
			Extension of life of mine, Unlocking more ore to mine
			Improved remuneration
			Less union activity
			Predictive Maintain ace
			Productivity
			Profitability
			Real time data
			Remote view of operation
			Resource increased by depth
			Smart Working
			Waste prevention
			Workplace diversity
	Business development	Opportunities	Automating production
			Automating processing
			Engineering services and maintenance
			Reskilling and avoid retrenchment
			Unlock resources
			Local Manufacturing
			Increased diversity at work place
			Attract investment
			Improve on Safety including fatalities
			Better jobs and remuneration
			Logistics and ore transport
			Utility management
			Mine dangerous areas
			Mine risk analysis
			New mines development
			Modernisation of current systems
			Digitalisation of mine process

Table 6: Research Question 3

Research Questions	Emerging Themes	Category	Codes
What are main hurdles and challenges in implementing these technologies?	Limiting Factors	Challenges	Affordability is a problem including development labour
			Bigger companies has capital to invest, small companies don't
			Technology is Complexity
			Country is lagging behind
			Development of skills, Robots are still far development
			Ethical issues, High level of unemployment
			Fear of technology, Robust equipment required, Mining Variability
			Global competition for labour, No ready equipment
			Mining is hostile environment especially underground
			Infrastructure, No immediate value, Limited skills
			Leadership not supportive, Poor political will
			Limited success in the country, Intervention priority is poor
			Potential Loss of employment, Ethical consideration
			Mining variability, Old Infrastructure, Old technology in narrow tabular
			Narrow tabular is a challenge, Physical environment limitation
			Obsolete quickly in changing environment, Resistance and Sabotage
			Project longevity and life of mine
	Limiting Factors	Mining Methods	Board and Pillar
			Trackless
			Surface
			Narrow tabular
			Tabular mine
			Narrow reef
			Room and pillar
			Mechanised
			Conventional

Table 7: Research Question 4

Research Questions	Emerging Themes	Category	Codes
What are the long term strategic decisions being made in support of AI, ML and AT ?	Strategy	Sustainability	Industry collaboration with suppliers
			Investment in technology
			Training
			Education
			Community development
			Respond with technology
			Drive Competitive advantage
			Relevant technology
			Respond to requirement
			Reskilling in other industry
			Stimulate other industries
			Introduce technology responsibly
			Collaboration with Government
	Leadership	Strategy	Leadership driven by
			CEO
			County President
			Digital first organisation
			Digital approach
			Culture
			Easy adoption
			Enabled environment
			Leadership
			Research and investment
	Skills development	Education and training	Create Meaningful jobs
			Train and develop skills
			Economic impacts
			Community based business development
			Skills transfer initiatives
			Cadet skills programs
			Match with stakeholders
			Workplace conditions improvement
			Empower Local communities in 4IR

Table 8: Research Question 5

Research Questions	Emerging Themes	Category	Codes
How do the implementation of these technologies affect the workforce demographics, worker relations and availability of jobs?	Skills Development	People	Attract and develop women in industry
			Reskilling
			Develop for other industries like agriculture
			Create skills for 4IR in communities
			Support skills for other industries
			Curriculum need to be changed to respond technology
	Diversity	Workplace	No physical strength required
			Technology Levels playing field
			More women
			Office as opposed to underground
			Opportunity to employ Disabled employees
	Industry development	Opportunities	Increased diversity at work place
			Improve on Safety including fatalities
			Better jobs and remuneration
			People removed from dangerous areas
			Improved relation, High skills less militancy
			New mines development
			Modernisation of current systems
			Digitalisation of mine process
	Limiting factors	Risk	Job losses
			Poor cognitive skills for technology application
			Difficult to implement
			Accountability
			Loss of experience
			Changing environment

Table 9: Research Question 6

Research questions	Emerging Themes	Category	Codes
How do you see the AI, ML and AT technologies changing the future of mining organisations in South Africa?	Industry Development	Future	Safety in a major requirement
			More mineable resources
			- Pillars
			- Deeper areas
			- Dangerous area
			Change perception of mining
			- Better and safe mining condition
			- Mining in airconditioned room
			- Effort replaced by cognitive ability
			- Potential to increase women in industry
			Highly skilled
			Increased Partnership with OEM
			Improve productivity
			Remote management, Automation
			School curriculum development
			Remote mining and management
			Government play a role
			Activate other industries
	Sustainability	Benefit	Safety, Safety, Safety
			Better business insight
			Better Quality of decisions
			Business sustainability, profitability
			Smart mines
			Less waste
			Drive competative advantage
			Efficiencies
			Extention of life of mine
			Improved remuneration
			Less union activity
			Resource increased by depth
			Workplace diversity

The final themes are established to be strategy, leadership, limiting factors, business development, industry development, skills development, diversity and sustainability. The themes and their relations is indicated into a thematic map shown in Figure 9.

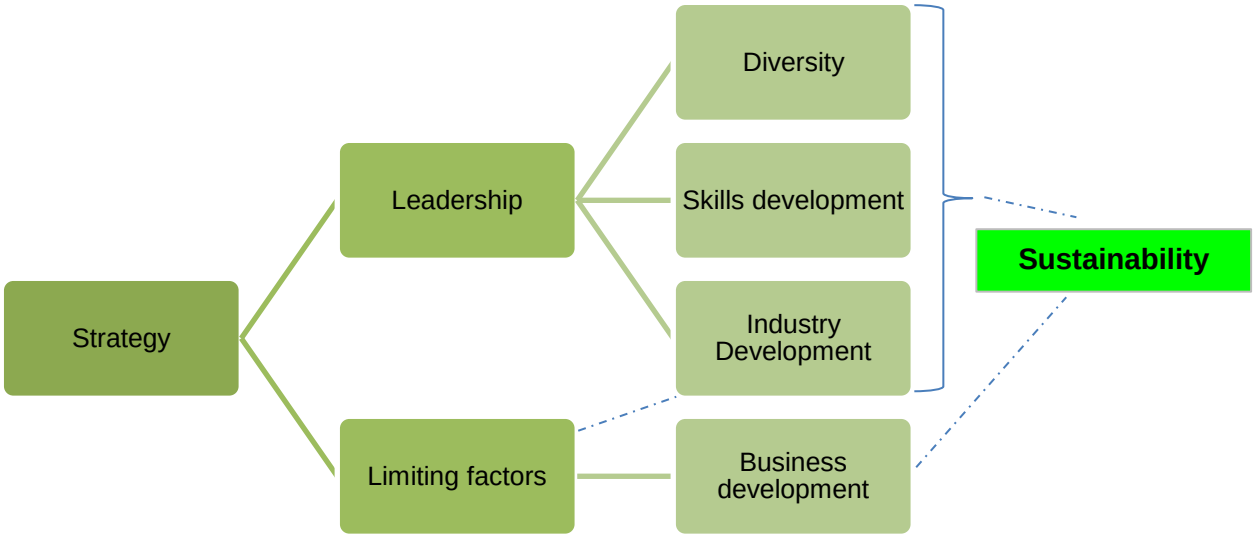


Figure 9: Thematic Map

4.5 Results approach to Propositions

In order to assess the propositions, the findings are derived from data collected which was dissected using the thematic analysis process. Therefore, to address each proposition, emerging themes are employed to further understand the phenomena. As part of thematic analysis process, there is provisions for formulating meanings and or definitions of each theme to assist in further understanding of the data pertaining to this study. For the purposes of this study, definitions are described under each preposition as tested by the instruments.

4.5.1 Results pertaining to Proposition One

Use of AI, ML and AT will have positive impact on mine production and people.

It is a general view form all respondents that there is opportunities for uses of AI, ML and AT in the mining industry. There is also an expectation of positive impact on production in mining and processing environment. It is also noted that inherent applications will require different set of skills, which will impact on people. Therefore, based on data to test this proposition, uses and impact of AI, ML and AT cannot be looked through a narrow view, but through emerging three themes of Strategy, Leadership and Business development. However, it is also imperative to note that none of the respondents indicated use of this technologies as a primary means of production at this stage in their respective mines.

4.5.1.1 Strategy

Strategy is by nature its some action required to achieve long term plans of an organisation. For the purpose of this study, action is based on three pillars of influence which include:

- Appropriate application of technology
- Technology as driven by AI, ML and AT
- and desired benefits

To realise uses of any technology, it must be driven by strategic and technological imperatives of the mining companies to ensure desired long term benefits are realised. However, respondent have divergent and converging ideas on how the strategy will impact on the uses of the AI, ML and AT in the mines. The responded from mostly class 1 to 4 mines are more positive about the uses of this technologies while those from Class 5 have reservation in the production environment although they see possibility in their processing plant.

The approach to technology implication will vary according to the requirement of the incumbent operation based on own established needs.

***"Resp 2** 'What we quickly relied on or what we often realise is that It's because of the nature of assets we have in South Africa, You cannot use a one size fits all approach, what we quickly realized was that you would need to have different deferent approaches for different commodities.'*

In order to realise specific uses to support development of the strategy is essential to take cognisance of specific areas, which require intervention as driven by inherent characteristics. For example, challenges experiences underground will be different to surface in some areas. Where similarities exist, the drivers might also be different. For examples, in the case of an antiquated mine that have been mined for longer period of time, where there is still opportunities, which can extent life of these mines with ore which is left behind due to depth or pillars from working stopes and or shaft pillars left to protect people, infrastructure, and equipment. Integrating people with technologies is also a factor, which can be driven by the strategy or simple digitisation strategies, which will enable smarter way of doing things, will be applicable to arears identified for intervention by this services and solutions. It is imperative to recognise that technology ought not to be complex, but can be integrated with simpler way of working. The use of tablets, sensors and application of smart utility services are opportunities associated with continuous mechanised equipment and use of real time management systems for operations. It is imperative to realise each technology will require appropriate support infrastructure.

Therefore, it is essential to identify and recognise issues which can be impacted by the 4IR technology so as to be able to achieve objectives of the company. If this is done correctly, specific and fit for purpose technologies will be applied, which will ensure desired benefit are realised.

Rasp 3 'we don't see ourselves in terms technology as leaders but we don't want be left behind to miss opportunities associated with benefit of safety, cost and productivity.'

The reality of technology is that there is associated benefit and with increasing cost, depth, safety, and factors of competitiveness will require that there is some

form on intervention driven by the strategy to ensure competitiveness in the industry. Although the approach is not inherently the first to implement technology, there are definite biases established to monitor what could be applicable to own operations to ensure sustainability of the business. The AI, ML and AT could be expensive. It is believed that in being the first to implement a given technology, cost can override initial financial benefit of the organisation.

Resp 2 '*I said companies don't have to automate everything, but should find out where are critical areas which requires interventions by putting in the supporting technology to which can be exploited by implementing required business strategy in order to meet business objectives'*.

It is no use to try and apply technology for its own sake, rather than identifying areas that will support the business objectives. An organisation needs to carefully determine those areas which require interventions, which are then driven by the business strategy where technology is at the centre of achieving the goals.

Resp 2 and 3 insists that there should be a rigorous needs analysis conducted in advance before consideration for application of the technologies.

Resp 4 '*Learn from other countries and encourage local innovation*.'

Benchmarking is seen as a gateway to encourage uses of the technologies while encouraging the local innovation. In the absence of local innovation and development of the industry, this will always force SA to be too dependent on other countries, and in the process, lose opportunities associated with the technologies. Old mine technologies are mostly old labour intensive. It will be nearly impossible to modify them to look and behave like AI, ML and AT.

Resp 5 *'Prices must be competitive'*

AI, ML and AT are not prevalent in the industry, but those that are being introduced tend to be expensive. The cost extent to infrastructure requirement which is an enabling interface. It is therefore imperative that a way should be found to drive the prices down so as to make the AI, ML and AT attractive.

Resp 6 '*it is essential to have partnership with OEM, seek buy-in from employees and ensure their community skills development*.'

OEM are an important element if uses of the 4IR technology are to be realised. The role played by OEM can encourage that appropriate technologies are manufactures taking cognisance of the conditions. There should be a partnership where specify technologies are discussed and where symbiotic partnerships to be formed. Internally employees must not be left behind and as they will ensure success for implementation. Communities need to be geared for the changes and facilitation of skills development, which are conducive to new direction must be cultivated.

Resp 7 'Modernisation, using technology to drive skills improvement and production.'

A change through modernisation of operation is important if desired benefit are to be realised. The transformation from antiquated mines to more modern mining application will drive long term strategic intentions. However, this requires parallel development of required skills.

Resp 8 '*Digital first organisation, digital approach to drive culture, adoption, enabling environment for people and leadership are important to drive the digital transformation*.'

To win in the digital space consideration should be taken so as to ensure a committed environment of deliberate ground rules of culture to foster better adoption as the technology is driven by people to ensure success.

Resp 9 '*Develop other industries like farming including upskilling outside of mining.*'

Government must be involved so as to ensure that other industries like agriculture are developed so as to ensure economy activity for people to minimise impact of employment opportunities. **Resp 4** also noted that mining industry can also distract focus on local agriculture. This is because mines tends to pay better. As a result, agriculture become compromised, which create social problems as mines cannot employ everyone.

4.5.1.2 Leadership

Leadership: this is central to the direction of organisation driven by functions identified to achieve strategic imperatives. This is underpinned by people and technology to ensure desires results are achieved with appropriate technologies and that inherent challenges are dealt with to ensure sustainability. Leadership extend to government as driven by the President of the country. It is believed that for the 4th industrial revolution to succeed requires leadership from the very top so as to ensure support for encouraging development, investment, and education.

Skills development and diversity: The development of skills is done so as to secure business sustainability aligned with AI, ML and AT within the company and communities to ensure a pool ready for employment if required. It also include upskilling and repurposing job description with implementation of new technologies. Consequence of this will then results in work place diversity, skills development and opportunities for women and people with disabilities.

Leadership is seen a major factor in driver of implementation of technology application, skill development and increased diversity in places of work. The responsibility extends to national government.

Rasp 4 '*Government* *and Country president must lead to support and delivery of the technologies to ensure country to be competitive.'*

It is recorded by Resp 4 that other countries are investing in technology to ensure development of the industry to contribute to the countries fortunes in the process develop skills and 4IR. Support at highest level will ensure that country is able to compete globally. Resp 2 noted that SA is still using technologies, which are over hundred years old. As a result, it is imperative for government to be involved. Resp 3, 10 and 12 also concur that the state must be involved.

Resp 11 *'It is important to have enabled environment driven by culture of digital first organisation underpinned by research and development.'*

It is important for the organisation to create an enabling environment to realise benefits associated with AI, ML and AT. To create this environment requires that organisation has the character of digital first approach supported by skills, infrastructure, and necessary investment.

Resp 14 *'Success for this technology requires visionary leadership at government and chief executive level to ensure successes.'*

There is not no doubt that to create success of the AI, ML and AT requires forward looking leadership. Bold decisions need to be taken especially all the way to government level. The incentive is required to encourage investment in the AI, ML and AT is paramount to support local development of skills and local manufacturing.

4.5.1.3 Business development

Business development: in this study is related to unlocking initiative to improve business through implementation of AI, ML and AT, which include AI, ML and AT as primary means of production in mining and process plants to achieve desired goals and benefits in this environment. This includes unlocking the value from previously unavailable mining areas, due to safety concerns, left out pillars, environmental conditions, costs, and increasing depth. Some of the intervention

will extent life of operation for instance if pillars are mined, and in the process, do so with higher level of efficiencies.

The results of antiquated mines, poor efficiencies, and safety concerns means there is inherent opportunities lost. Therefore, some intervention through use of various AI, ML and AT could unlock this opportunity.

Resp 1 '*Automation will allow for work in unsafe conditions'*

The opportunities for automation are significant due to complications of safety with resulting increasing depth, poor efficiencies, and interrupted production requiring some this kind of intervention. The threats of large truck interfacing with small cars and people create a potential for risks and accidents.

Rasp 2 '*an opportunity to unlock resources and limit control of environmental exposure.*'

Mining is a finite resource with inherent design, which leaves remnants and pillars left for purposes of safety and stability of excavations to protect people and equipment. In surface mines, there is also risk associated with depth where in deeper areas of the pits, side can collapse of people and equipment. Therefore this inherent challenges can lock opportunities.

Rasp 3 *'**Access to dangerous working places to unlock more resources*.'

Safety is a contentious issue in the mining industry, with a very bad history of incidences of damage to properties, injuries, and fatalities, which has impact on production and productivity. Opportunities associated with automation can unlock areas which are considered unsafe include mining at depth.

Resp 4 'Also note that low-grade areas will be unlocked which will increase the life in the process and also change the labour dynamics with more women being included in the mines.'

Resp 5 'there is opportunities which will include continuous production, which because the current system uninterrupted by an inherent system.'

The current mining cycle in its simplest form consist of drilling, blasting, cleaning, and support. The functions are not continuous, following each other intermittently with blasting, which requires a longer break, due to blasting fumes that have to clear before any work can commence. Therefore, opportunities associated with automation tools can ensure people are not involved in the production environment, but conduct work from remote areas. The value associated with remote mining include safety, productivity, efficiencies, lower costs, and continuous production.

4.5.1.4 Conclusion to Proposition 1

In order to realise positive impact on process and people, it is important to drive this through carefully thought-out strategy, which drives the application of technologies to impact in processes. Leadership is an essential component not restricted to the CEO but also at the head of government, to drive an enabling environment, which will ensure quality jobs, increased diversity, and increase in skills through the encouragement of other industries.

Strategy and business development are proving to be essential in driving business goals through improved efficiencies, costs, safety, and unlocking other areas which is an avenue of business development. Areas considered unsafe, pillars and deeper virgin areas of mines would be able to be developed further by the use and adoption of this technologies.

The respondents from class 1-2 mines have a higher proclivity toward adaptation of this technology development and its application. They are already mechanised using mine equipment for many of their tasks. However, those from Class 5, have less inclination towards adaptation of these technologies primarily based on the nature of the ore bodies, which are considered complex due to their unique geology. It is also established that there is realisation that commodities are different in their characteristics and will have to consider their critical needs to identify areas of interventions using this technologies.

To realise the impact, benchmarking with other industries, price competitiveness, partnership with OEMs and government will ensure the advancement of the industry, in the process support long term strategies, which foster a culture of digitisation accompanied by many benefits. Business development will be able to unlock other areas including long term business plans, which will unlock value of the operations previously unavailable.

4.6 Results pertaining to Proposition two

Implementing AI, Ml and AT technologies will have to overcome inherent challenges to realise the benefits

AI, ML and AT has opportunities to unlock value for mining organisations when implemented. However the industry is considered lagging compared to others, due to a number of factors. There are serious challenges that interfere with progress in this part of the development. The limiting factors and industry development will play a role in creating fertile ground for adoption of this technologies.

4.6.1.1 Limiting factors

Challenges that impede implementation of appropriate AI, ML and AT to achieve desired goals and benefits as part of strategic imperatives. The limiting factors are further categorised below into people, which include perceived risks, mine design, and inherent adoption challenges.

People: The dilemma of ethical considerations is a big issue, which is mostly driven by potential job losses. Generally, respondents agree that there is going to be impact on employment, which will contribute negatively to already worsening socio economic impact in the country. However, loss of employment in Class 1 operations will be smaller than conventional mines, due to smaller number of employees. Class 5 is labour intensive and is expected to shed more employees.

Resp 12 *'it is expected that with these technologies there is going to be job losses although it might create others somewhere else'.*

Resp 3, 5, 14, 13 and 11 share the same sentiment. *'The approach is reskilling, gradual introduction of technology and redeployment where possible to limit impact. In essence create jobs along the value chain.'*

Resp 2's approach however is slightly different, believing that jobs loss should not exist. *'Infuse current jobs with technology to task easier for the employees.'*

Rasp 4 *'Mechanised mines have proven to employ less people as equipment does bulk of the work. Impact in this area will be less. However conventional mines with its labour-intensive work, job losses will be much higher if some of these technologies are adopted.'*

Inherent challenges: The design parameters created an existing environment which will have to be infused with implementation of AI, ML and AT. This includes existing infrastructure, way of working for labour, services and other functions, which will ultimately create success of the business. The challenges of this are discussed below

Capital outlay: It is a critical challenge that the transition into digital realm is capital intensive. Class 1 mines have an advantage of easy access to networks where close to cities, while Class 2-5 will require more capitalisation to improve on their CN, OT and IT infrastructure but still considered expensive. All respondents, agree that cost of the technology is expensive. However, in the main, large mining companies will have the capacity to implement these technology while small companies will find it difficult due to costs.

Resp 1 *'Technology is expensive'.*

Resp 5 *'there is no drive to implement this technology due to the costs involved.'*

Resp 9 *'Capital also include hardware, application and specialist skills required being international can be expensive.'*

Resp 10 *'also concurs that labour is often not included but it is a huge cost which include developmental costs.'*

Resp 11 *"Cost seem to be unjustifiable considering life of the projects.'*

Infrastructure and Supporting devices - Infrastructure is paramount to enable application of this technologies successfully to realise the benefits. Enabling devices for Class 2-5 must be robust for instance while those in Class 1 can easily employ available ones in the market intended for general use. Connectivity between the devices, equipment and environment is essential to allow for benefit of real time view which is one of the major component of the technology.

Resp 1 *'Infrastructure is important to facilitate application of this technologies.'*

Resp 5 *"there is plentiful cheap labour in SA as compared to highly expensive but attractive skills which is attractive to support technology.'*

Resp 6 *'There is general lack of infrastructure in the industry in general.'*

Resp 11 *'Unfortunately some remote areas infrastructure does not exist.'*

Resp 10 *'some areas have old infrastructure which will require some intervention to make it work for the technologies.'*

Resp 12 *'Connectivity and Infrastructure is a problem and not really catered for. This has to be corrected to create an enabling environment.'*

Resp 2 *'technology must not be seen as complex, as use of tables can be infused in underground situation to facilities reporting for instance. However this must be robust as the conditions are rough.'*

IT infrastructure is a backbone technology, which requires intervention and investment for all classes of mines where challenges of connectivity exists.

Variability - In class 2-5 mines, the process is highly dynamic due to continuous development of excavation for access tunnels and mining out on ore horizons. In

some areas, ores not homogenous creating a conundrum of variability making it highly variable in grade and geological complexities.

Resp 1 *'changes in same mines cannot be ignored with even distinction within similar type of commodities including changes in chemical composition and complex geological physical structures, which include activities of undulations, faulting and dyke faults, which impact on consistency of the ore bearing rock formations.'*

Resp 11 '*Mining ore bodies are not homogenous, the sudden changes impact immensely on processing plants, with AI algorithms becoming obsolete within a short period of time.'*

The ever-changing conditions makes it very difficult to plan some of the functions required for these technologies due to dynamicity of the inherent ore bodies.

Mine Classes - Challenges of Class 1 mines and those of classes 2-5 differ. Classes 1 - 4 are seen to be more amenable to digitisation, as they already use advance mechanised equipment to carry out tasks. The challenges of Class 5 is much more complicated as a result uses old mining technologies which will be more difficult to digitise. In classes 2-4, there is hope as this equipment can be modified and use of AI technology can be infused, as seen with use of VDS and PDS, which was prescribed by DMR in response to issues of safety. Currently this the technology is employed in classes 1 to 4, operations where mechanised equipment are used.

Resp 12 *'Mechanised mines will be easy to convert to digitalisation as they utilise equipment, which can be infused with other technologies.'*

Resp 10 *'please note that at this stage gold mines does not see real value at this stage due to current type of technologies which will be difficult to digitise as they are mostly labour intensive. Things like robotics will take a very long time to implement much longer than 20 years minimum due to complexities of narrow tabular ore bodies.'*

Respondents in Class 1 to 4, have some experience with VDS and PDS which are implemented as a prescribed by DMR due to safety concerns in the mines. Resp 1, 5, 6,7,8,9 and 14 all have these two systems employed in their mines, which are for safety purposes, so as to avoid dangerous interface between vehicles-vehicles and people.

Resp 4 *'Underground environment is hostile and there no readily available equipment to support it.'*

Resp 12 *'Unfortunately there is not readily available data for comparative studies at this stage. Building data will take a long time. In the absence of local data which motivate for the employment of this technology. This will create dependence on outside support and services.'*

Skills - Technology can be complex, which requires a higher skills set, which is not readily available. In its absence, therefore, international market will have to be pursued for purposes of recruitment, which comes at a cost and risk. Internal skills are exposed to global environment, making them difficult to retain them for longer period of time.

Rasp 5, 6, 8, 9, 10 and 12 conquers that there is a skills deficit in the country to support this technologies. Statements used to describe this problem from respondents include severe skills shortages. Skills are a huge challenge, due to poor skills in the country. Specialist skills are necessary and we don't have at the moment and lack of skills will create costs impact.

Skills are one major factors that will require development in order to overcome as a limiting factor.

SA is sluggish – the country is lagging behind in development, skills and adaptation of AI, ML and AT. Digital transformation requires leadership at government level, and a CEO to drive initiatives to drive implementation of this technologies.

Resp 12 *'SA is lagging behind other countries in terms of development of AI technologies. This is because there is poor leadership at government level and CEO level within companies; it also important to note that digital transformation requires visionary leadership.'*

Resp 6 *'There is poor grasp and understanding of these technologies especially from company CEOs.'*

Resp 3 *'It is important to drive local innovation and learn from other countries. It is also will be encouraging to have political will with leadership at government level. The CEO must be the driver within organisations.'*

Major stakeholders - Government and Unions can contribute to the sluggish attitude towards this technologies due to the potential loss of employment. Lack of stimulation by the government create a loss of opportunity for the country where benefit associated with digital transformation.

Resp 3 *'People are a strength of the union, therefore inclination toward this technologies will impact on membership numbers which will render unions useless in the future'.* Resp 4, 5 and 10 concur with this assertion.

However, Respondent 2 has divergent insight, namely that unions are able to move past their own needs, and embrace these technologies.

Resp 2 *'In the absence of safety solutions and continued exposure to workers, this leave little choice for unions to look the other way. Through our organisation, we find that unions are more amenable to technologies changes which contribute to the wellbeing of their members.'*

Resp 10 and 12 believes that Government must play an active role to support digital transformation and in the process stimulate the industry.

4.6.1.2 Conclusions to Proposition Two

Limiting factors are major contributors to lack of appetitive for adaptation of AI, ML and AT in the mining industry. An ethical consideration raised by one of the respondents, mostly driven by potential of job losses, is exacerbated by existing poor socio-economic conditions in the South.

Implementation of AI, ML and AT comes at a huge cost, which carries with it expensive skills requirement for development, along with infrastructure and implementation requirements. The constant variability inherent in these systems is major concern, as these changes will impact on things like AI algorithms impacting intended benefits.

By their nature, mines are established with design attribute considered feasible at the at study stages, which include excavations, equipment utilised, utility services, and the way in which tasks are performed. This will be a great challenge to then undertake digital transformation, although it is generally accepted that it will be much easier in class 1 to 4 mines, while class 5 mines will require much more due to their ore body challenges, which are complex and thin and also labour intensive, with primitive and manual equipment. Some respondents feel that this category will take time to digitise, and it is also considered unimportant, offering little value.

Skills are a major concern, with a large swathe of ground required in creating systems and algorithms that will make equipment work, supporting AI, ML and AT in the industry. At this stage, this skill is lacking and will come at cost and increase risk to business, as these skills are dispensable.

Leadership is found to be wanting, due to its misunderstanding of what's required to achieve many benefits associated with this technologies. Government also seem to be sluggish in creating space for technologies to be successful. It is required that at government level, the President of the Republic should be driving and stimulating the industry to make it competitive. CEOs are required to also create a culture of digitalisation in their organisations.

4.7 Results Pertaining to Proposition Three

Strategy decisions will drive sustainability and secure future of SA mining industry by using AI, ML and AT

4.7.1.1 Sustainability

Sustainability: The inherent challenges of safety, lost resources due to design, costs, lack of investment, and poor growth of the industry will have to impact upon by this technologies to ensure industry sustainability in SA mining industry. It is expected that having the ability to motivate and show application of various fields, its benefits, drivers, and impact areas will ensure appropriate motivation for increased investment, and ensure continued sustainable exploitation of the industry done in a safe, efficient, cost-effective manner, with the ability to further unlock other resources, which by design or limitation of technology may be considered to be unavailable. There are a few elements which further support the concept of sustainability pertaining to this study which include strategy, application, benefits, drivers, and impact areas. The strategy is addressed in **section 4.5.1.1 above.** The elements indicated will be used to address the preposition in this section.

Application - for the purposes of this study the field refers to uses and application of AI, ML, and BD and AT. Definitions are addressed in Section 2. In these section only applications will be considered.

Resp 1 *'I am expecting to see ML, Drones, AI driven process to improve and impact positively on production and safety.'*

Resp 2 ***'****If you are looking at application scope, the technologies in mining environment will include digitalising reporting, predictive maintenance, real utilisation data for equipment, environment measurement for gasses, real time figures on production, mine planning and modelling, training, drilling, and trucking.*

These functions encapsulate AI (digitalised reporting, environmental monitoring, training), ML and BD (predictive maintenance, Planning and modelling), and AT (drilling and trucking).

Resp 3 *'The application are vast by just to name a few will of the technologies, Remote mining, Data capturing, Data management, Real time data management, Travelling, Drilling activities, survey, unmanned technology in production and ore extraction from dangerous areas.'*

AT (Remote mining), BD/AI (data management, real time data management), AT (unmanned technology, extraction from dangerous areas)

Resp 6 *'I believe that remote drilling, ore trucking and data harvesting for insights are critical in production.'*

AT (remote drilling and trucking), BD/AI (Data harvesting and insights)

Resp 10 *"the functionaries of AI, ML and AT can be introduced in ore transport, reporting, data analytics, mine, processing plant and production cycle (cleaning, drilling and blast, loading, ore transport), which is expensive.'*

Resp 11 *'this areas of AI, ML and AT can be employed in exploration, environmental management, consumables and ventilation, which will be driven by demand.'*

Resp 12 *' there are huge scope for this technologies which are not limited to this ones I name, which include processing plant, equipment maintenance, management of mine services, flooded mines, transport, machinery and equipment, seismicity, real time mine monitoring for gasses, pro-active decisions and production with less people.*

AI/BD (processing plant, maintenance, seismicity, real time monitoring, decisions), AI (utility services management), AT (production with less people)

The respondents concurs with the summary above and strongly believe on use of AI, ML and AT applications, which can contribute to sustainability of the operations.

Benefits and Drivers - benefits refer to advantages that will make the industry competitive and sustainable. These are some of the factors contributing to the demise of the industry. Things like costs, poor efficiencies, lost opportunities due to design and unsafe areas destroyed the value preposition from the industry. In current operations what will be the motivation to transition to this technologies. The two variable are similar, and address the same concerns, as a results the research choose to treat and address the proposition as seen by the respondents.

Therefore, the benefit and drivers will be further be divided into the following elements, which are common amongst the respondents:

- Safety is a big problem for the industry as with many recorded fatalities, injuries and damage to equipment, which impact heavily on people but also production, costs, and poor efficiencies. As a results the application of these technologies have the following benefits:
    - Through AI and AT technologies, remove people from dangerous working places;
    - Minimise exposure of exposure to dangerous gases with AI monitoring sensors in working areas;
    - In response to DMR prescribe, AI driven PDS and VDS are already in place to prevent dangerous interface between people and vehicles in the process preventing harm to people and or damage to equipment; and
    - Unsafe areas can be mined with AT especially pillars and other deeper virgin ground which is unknown but could have consequences of safety for people.
- Improved Production, Productivity and Efficiencies as driven by functions of AI, ML and AT in the production environment, where poor result will be able to be addressed.

  - Increased time efficiency with continuous uninterrupted cycle in the production environment through use automated equipment;
  - Improved reliability with AI driven by predictive maintenance;
  - Mining products to be homogenous contributing to better efficiencies in the production and processing plants
  - High equipment utilisation and improved accuracies;
  - Producing more with less; and
  - Efficient use of utility services of water, ventilation and electricity.
- Business Development for the purposes of this study, refers to areas which can be developed and add life of the mine.
  - Dangerous areas like pillars can be mined without compromising safety but only adding value to the business by extending resource count;
  - Mining of deeper virgin ground;
  - Increased payback period with more value realised in short period of time due to continuous operations and increased efficiencies; and
  - Remote operating of operation where skills could be shared amongst sites.
- Lower cost of operations improvement driven by AI, ML, BD and ML, which are impacted with increasing efficiencies in the system.
  - Using AI for procurement process to ensure seamless operation in acquiring data and dispensing functions of invoicing, payment and acquisition of products require to support the business. This includes interfacing with engineering aspects such as predictive maintenance.
- People will impacted both negative and positively in application of this technologies. However, people employed in the environment driven by technologies will have benefit which in the main will contribute to social economic benefits. The benefit include the following:
  - Better pay, which will narrow gaps in employment inequality;

  - Improved workplace diversity where cognitive strength is utilised rather than jobs which can be done by males;
  - Technology will be equaliser in the workplace with minimum disparities of pay between employees;
  - Jobs will be meaningful.
- Engineering is responsible for utility services and equipment utilisation which include maintenance. Application of this technologies will improve and create the following benefits:
  - Predictive maintenance is a big one which instantly improve in machine availability for production;
  - Less waste in the system as parts will be ordered when required based on real data
  - Utility services efficiencies which will be dispense appropriate when required;
  - Waste of utility services like water and ventilation will be acted upon immediately with Improved real-life monitoring; and
  - Real time monitoring and appropriate responses.
- Mine Planning is informs long-term, medium and short-term planning to guide business navigation. With technologies like AI, ML and BG ore bodies will be planned to create better life of mine plans based on real and changing data which contribute to business strategy goals of safety, profitability, and sustainability. Gathering of information from mining areas can inform production on how to approach areas with seismic impact change in grade distribution.
- Digitalised reporting will improving on how data is received and compiled to ensure various benefits which include:
  - Quality decision based on good information driven by AI, ML and BG;
  - Data is real and instantaneous allowing for quicker reaction time; and
  - Improved business insight for short- and long-term planning.

Benefit and drivers are real and would impact positively on the success of the business.

Impact – this area identified by respondents which be impacted by these technologies of AI, ML, BD and AT in their operation and various. The impact areas are must should be requiring intervention of influence to realise benefit of this technologies.

Resp 1 *'area I think will add most impact include Production life cycle, in mine planning for Mine schedule, in engineering especially Maintenance, security and management of consumables.'*

Resp 2 *'Areas which exposes people to noise and dust are critical to ensure safety of people.'*

Resp 4 *'Safety is a concern. Dangerous working areas like Deep mines, Mine pillars will contribute to business without harming people.'*

Resp 5 *"Both surface and unground mines can benefit from this technology as per own requirement and need.'*

Resp 10 *'There is opportunity for AT in Ore trucking and locos underground. The old narrow reef technology equipment and processing plant is another area of impact. Plant are mostly ideal as the static like manufacturing plants.'*

Impact areas are vast along the business value chain, which offers an opportunity for intervention of employing a combination of this technologies. However, there is a need for each area to establish their own areas which can be impacted by the technology in order to advance goals of the organisations.

4.7.1.2 Industry development

It is essential that the industry is supported to ensure challenges associated with issues of safety, dangerous mining areas, and mining technology limitations, especially where virgin and deeper resources and left out pillars pose a risk to people, primitive processes, and old technologies especially in antiquated Class 5 mines. A collaborative approach between miners, government and stakeholders including unions support initiative to revive the industry and make it more attractive.

Resp 4 *'Mining has a badge of poor safety and with fatalities giving the mining a bad image. Therefore a change of perception of mining, improvement driven by better and safe mining condition like mining in air-conditioned rooms remotely, making sure effort is replaced by cognitive ability and this will potentially increase women count in the process increase diversity.'*

Resp 5 *'A holistic approach is necessary with training of people, ensuring prices of technology are down, increase users of technologies, operating conditions must be met and supported by strong business case.'*

Resp 6 *'Since there no equipment available for some of the tasks, early partnership with OEM is critical to meet industry needs.'*

Resp 7 *'With the technologies remote management and mining is possible. However education and School curriculum must be changed to gear towards skills development at early age. Government role is paramount and must play a stimulating role. The impact of job losses is real, however with government participation other industries like agriculture can be activated to ensure employment of the country is not impacted.*

4.7.1.3 Conclusions to Proposition Three

The inherent challenges of safety, lost resources and opportunities, costs, lack of investment, and poor growth of the industry require intervention by the technologies to ensure industry sustainability. In order to secure the sustainability of the industry, major challenges must be addressed. Based on insight from the study, there are few elements of impact in the operations, motivation which is include benefit and drivers for application of the technologies and industry development.

Opportunities of impact areas include production life cycles, logistics, processing plants, and all areas of which contribute to poor safety and exposure of people. The benefit and drivers are immense, which include prevention of injuries and fatalities (safety of people) and damage to properties which has impact on productivity and costs. Improvement of production, productivity and efficiencies will contribute immensely to business sustainability. People are also impacted positively with many benefit associated with improved diversity, better salaries and safe operating conditions. Predictive maintenance and management of utility services will improve overall costs and prevent wastage in the system. Mine planning driven by AI, ML and big data will contribute actively to life cycle planning and with real time reports improve on quality of decisions which support business sustainability.

It is essential that the industry is supported to ensure challenges of safety and mining technology limitations are impacted by application of these technologies. A collaborative approach between miners, government and stakeholders including unions must support initiatives to revive the industry and make it more attractive. Government is expected to play an important role in stimulate the industry to support transition to digital transformation. CEO as leaders of business must play an integral role in understanding technologies, identifies areas of concern, and develop strategies which include use of AI, Ml and AT in order to realise business objectives.

4.8 Summary of findings

Propositions 1: Use of AI, ML and AT will have positive impact on mine production and people.

Fundamental emerging themes of strategy, leadership and business development are apparent in addressing preposition 1. In order to realise impact on process and people, a careful strategy is required based on need analysis to establish goals, which will be driven by positive impact of AI, ML and AT on mine production and people.

It is also established that leadership must be driven by CEO of the organisation to drive an enabling environment and culture which will ensure impact on quality jobs, increased diversity and skills. It is also imperative that appropriate technology is employed to achieve company goals. On a macro level, visionary leadership is required to drive digital transformation to support dwindling industry like mining to realise impact of using these technologies, which offers benefit of safety and efficiencies.

Fit for purpose strategy, business development, and appropriate technologies impact positively through benefits of improved efficiencies, costs, safety and unlocking of value in the business. Areas considered unsafe, pillars and deeper virgin areas of mines would be able to be developed further by the use and adoption of this technologies. Business development as an emerging theme informs the approach towards long-term planning. It is critical to unlock value associated with risk areas of which can be included on long term business plans and was previously unavailable.

Propositions 2: Implementing AI, ML and AT technologies will have to overcome inherent challenges to realise the benefits.

Limiting factors are major contributors to lack of appetitive for adaptation of AI, ML and AT in the mining industry. Emerging elements include ethical consideration driven by potential of job losses under existing socio-economic conditions in SA is one of a major concern by respondents. Capital expenditure for enabling environment is considered high, and in some arears unjustifiable. Continuous changes driven by ore body complexities in grade, chemical composition and structure makes it difficult to plan in order to adapt with fixed rules.

Digital transformation of already existing systems could be a challenge as the design parameters did not anticipate future conversions as dictated by technology. Skills shortages will be costly, creating risk to business due to global competition.

Leadership is found to be wanting due to its misunderstanding of what's required to achieve many benefits associated with this technologies. Government also seems to be sluggish in creating space for this technologies to be successful. It is required that at government level, the President of the Republic should be driving and stimulating the industry to make it competitive. CEOs are required to also create a culture of digitalisation in their organisations.

Propositions 3: Strategy decisions will drive sustainability and secure future of SA mining industry by using AI, ML and AT

The inherent challenges of safety, lost resources and opportunities, costs, lack of investment, and poor growth of the industry require intervention by the technologies to ensure industry sustainability. Strategic decisions takes cognisance of elements, which support long-term sustainability of the industry. These include strategy as driven by appropriate technology, desired benefit, and drivers and industry development.

It is essential that the industry is supported so as to ensure challenges of safety and mining technology limitations are impacted by application of these Technologies. A collaborative approach between miners, government, and stakeholders including unions must support initiatives to revive the industry and make it more attractive. Government is expected to play an important role in stimulate the industry to support transition to digital transformation. CEO as leaders of business must play an integral role in understanding technologies, identifies areas of concern and develop strategies which include use of AI, Ml and AT in order to realise business objectives.

CHAPTER 5. DISCUSSION OF FINDINGS

5.1 Introduction

In this Chapter, the examination of the research results presented in Chapter 4 of this study are conducted. In addition, the approach is to show insights derived from literature study Chapter 2 and superimpose the results originating from the empirical study. For this reason, the results are presented in relation to the proposition which considers the research questions. **Table 10** below summarises Research questions, propositions and final themes.

Table 10: Research Questions, Propositions and Final Themes

Research Questions	Proposition	Themes
What are the long term strategic decisions being made in support of AI, ML and AT	***Use of AI, ML and AT will have positive impact on mine production and people.***	**Strategy Leadership Business Development**
How do the implementation of these technologies affect the workforce demographics, worker relations and availability of jobs?		
What are main hurdles and challenges in implementing these technologies?	**Implementing AI, ML and AT technologies will have to overcome inherent challenges to realise the benefits.**	**Limiting Factors**
What are the potential uses of AI, ML and AT in mining industry?	**Strategy decisions will drive sustainability and secure future of SA mining industry by using AI, ML and AT**	**Sustainability Industry Development**
What are major impacts areas of implementing these technologies?		
How do you see the AI, ML and AT technologies changing the future of mining organisations in South Africa ?		

5.2 Discussion pertaining to Proposition 1

Use of AI, ML and AT will have positive impact on mine production and people.

5.2.1 Strategy

The emerging themes from the empirical study highlight the importance of developing a strategy that recognises challenges faced by the organisation. Strategies developed should then trigger appropriate technologies to respond for purposes of address and then realise long time benefits on the organisation.

From the literature review, a study conducted by Lane, Guzek and Van Antwerpen (2014) identifies challenges of declining ore grades, increasing cost of extraction, increase depths which introduces additional safety issues due to the rock falls, flooding, gas discharges, earth tremors and ventilation problem. A DMR(2020) report also further shows that safety is a major concern with mine fatalities between years 2018 and 2019 reaching 132, including 4 853 occupational injuries,1 974 deaths from occupational related incidences, and 7 968 recorded occupational diseases in the same period. Labour unrest can be a challenge, with the Marikana Massacre resulting in 34 miners killed and up to 78 injured (South African History Online, 2012).

Form the empirical study, the data indicate the importance of doing a deep analysis to establish specific requirement to ensure that appropriate technology is implemented. It is imperative to therefore consider this the deep analysis using TOC for the purpose. In adopting the TOC there is opportunity to secure solutions driven by AI, ML and AT to eliminate constrains. Where exposure and consequence of fatalities is experienced, perhaps an AT solution can be employed where people are removed from harm's way in the process removing risk of fatalities and creating a safe environment.

The study further highlight that to solve these challenges, leadership is central to the success of implementation of the long term strategies.

5.2.2 Leadership

Leadership especially from the CEO level must drive the strategy and technology application. In addition, skills development is essential to address requirement and in the process improve employee experience at the places of work environment. Leadership is seen a major factor in driver of implementation of technology application, skill development and increased diversity in places of work. Impact of employment cannot be ignored, however the industry has been haemorrhaging jobs according to (Statssa, 2018) report. Jobs losses already dropped incredulously by 41% from 1987(780k) to 2018(456,44K).

The literature study indicate that there is motivation for pursuing this technologies. A study by Hyder and Siaun (2018) argued that one factor that can boost the growth of mining sector and make it more lucrative to investors is the application of AI, ML and AT in the mining sector. It is puzzling that leaders in the industry are not aggressive pursing this technologies which can deal effectively with challenges. There is an opportunity to improve on mine production but there is still hesitancy in the industry which is driven be number of factors discusses in 5.3.1

In manufacturing, a study by Wuest, Irgens, Klaus-Dieter and Weimer (2016), found that old manufacturing plants were rejuvenated by several initiative which propelled application of AI and ML. The results were successful intelligent and smart manufacturing. The mining industry in SA some is important and it has the opportunity to increase its share of contribution to the economy of the country with appropriate intervention. The results of the data shows that leaders must pursue learnings from other industries for cross pollination of knowledge.

5.2.3 Business development

Business development is considered important in unlocking areas previously unavailable to be mines which can now extent life of mines through efficient, safe and low costs created by these technologies. Dangerous areas, left out pillars and deep virgin ground can be unlocked to impact on increased resources which will form part of the business plan for exploitation.

5.3 Discussion pertaining to Proposition 2

Implementing AI, ML and AT technologies will have to overcome inherent challenges and hurdles to realise the benefits.

5.3.1 Limiting factors

The research corroborates that appetite for implementation of the AI, ML and AT is low at this stage. Although the study indicate interest and comprehension of potential benefit, none of the classes of mines have any of the technologies footprint as a primary means of production. A study by Lottermoser and Barnewold (2020) indicated that analysis of 158 active surface and underground indicate poor uptake of the digital technologies. In addition, a study by Hyder and Siaun (2018) found that there is potential for AI, ML and AT technologies to bring a new revolution into mining industry by reducing cost, improving productivity and efficiency through use of intelligent systems.

Another study by Sganzerla, Seixas and Conti (2016), found that challenges of market volatility, changing global demand, remote reserves, a focus on a longer asset lifecycle and a commitment to operational excellence, policy shifts around the globe, decades of cost reduction and the aging workforce have left mining companies with limited resources. Based on these facts, industry was supposed to be pushed towards a seismic shift to digital transformation. However, mining companies are not fully taking advantages of this development.

In comparative industries to mining, like construction and manufacturing, it can be established from literature that both recognised importance of this technologies, however on the part of construction there is a low appetite comparable the mining. The reluctance for adoption in construction can be seen from findings by Akanbi et al. (2019) that economic, technical and cultural dynamics and weak business cases are inhibiting factors. However, in manufacturing these technologies have been embraced with real benefits.

The benefit from manufacturing sector summarised from the literature review:

- Findings of Skrop, Holczinger, Bakon, Mihalics, & Jaskó, 2018 found that digitised factories makes it possible to monitor all the physical processes in *real time and make effective decentralised decisions*.
- Bajic et al. (2018) finds benefits of the application of ML lead to the achievement of *defect-free and fault free processes*. Other areas of impact is *optimisation, security, and cost reduction without affecting quality of production.*
- Sweden, Gryth and Runderbug (2018), found that AI is enabling automotive companies to leverage which impact on *strategic decisions and positioning*.
- Key findings by Wuest, Irgens, Klaus-Dieter and Weimer (2016), indicate that inefficiencies and poor old designs have rendered manufacturing sector uncompetitive in the USA. However, several initiatives propelled by ML and AI development led to concept of smart and intelligence manufacturing which *improved on performance*.
- Skrop, Holczinger, Bakon, Mihalics, & Jaskó (2018) indicate that a smart factory makes it possible to monitor all the physical processes in *real time* and *make effective decentralised decisions.*
- Luxembourg by Singh and Arat (2016), key findings, indicated that with increase collection of data, DL will play a huge role virtual sensing for vehicle dynamics application, vehicle inspection and heath monitoring, automated driving and data-driven product development which key areas that are expected to get the most attention.

In the context of both extant literature and the current study, there is a common denominator of poor adaptation of this technologies. In comparative industries, construction have similar posture to that of mining while manufacturing has embraced the technologies. Therefore, to establish insight from the study, we have to look closing at the factors limiting implementation of this technologies in SA mine operations. Having adopted TOC for the purpose of this study, it can be observed that the identified limiting factors are actually constraints which affect the mines one way or the other.

Summary factors from the study are shown as follows:

- **People** - The dilemma of ethical considerations mostly driven by potential job losses which will further fuel unequal society and exacerbate already compromised socio-economic issues in the SA.
- **Inherent challenges** - digitalisation of currently stable mining operations is a challenge as business cases for investment did not foresee future of digital transformation. As a result, changes will require a total rethinking in process, which will support operation of the technology, including the reskilling of labour, acquiring ready or modifying existing equipment to ensure infusions with capabilities of this technologies. In the absence of real data use of international organisation and similar industries will have to be exploited to source and transfer usable equipment to accelerate digital transformation.
- **Capital outlay** - is considered a huge challenge and in some areas in not considered justifiable based on things like life of mine and value add initiative. It is, however, expected that once a causal link and confidence of real data and benefit arises large corporate mining companies will be able to invest in this technologies. The case cannot be made for smaller companies, where every cent must be counted to contribute to the mines

to realise value. This technologies will have to also compare with readily availability of cheap labour.

- **Infrastructure and Supporting devices** – Infrastructure (CN, OT and IT) is paramount to enable application of this technologies successfully to realise the benefits. Connectivity between the devices, equipment and environment is essential to allow for benefit of real time view which is one of the major component of the technology. Classes 2-5, which are mostly unground, will require a bit more investment as the environment and will require rugged equipment and infrastructure.
- **Variability** - mine processes are highly dynamic due to continuous development of excavation for access tunnels and mining out on ore horizons. Networks will have to be extended to keep up all the time especially for class 2-5 mines. Ores are not homogenous creating a conundrum of variability, which makes instable in grade and geological characteristics, which will then require continuous technical changes for instance in managing AI driven algorithms. The changes will be difficult as they will require data. A study by Duin, Meers and Gibson (2007), found that in many instances, there was high variability in mining conditions for the same processes. Therefore the different variables will require different solutions and as a result creating lack of integration if AT is used.
- **Mine Classes** - Challenges of Class 1 mines and those of classes 2-5 differ. Classes 1 to 4 are seen to be more amenable to digitisation as they already use advance mechanised equipment to carry out tasks. The challenges of Class 5 is much more complicated as results use old mining technologies, which will be more difficult to digitise. In Class 2 - 4, there is hope as this equipment can be modified and use of AI technology can be infused as seen with use of VDS and PDS which was prescribed by DMR in response to issues of safety. Currently, this technology is employed in class 1 to 4 operations, where mechanised equipment are used for purposes of safety.
- **Skills** - Technology can be complex, which requires a higher skills set that are not readily available, where in their absence the international market

will have to be pursued for purposes of recruitment, which comes at a cost and risk. International skills are exposed to global environment making them difficult to retain them for longer period of time.

- **SA is sluggish** - the country is lagging behind in development, skills and adaptation of AI, ML and AT. Digital transformation requires leadership at government level and CEO to drive initiatives to drive implementation of this technologies.
- **Major stakeholders** - Employees, Unions and Government can contribute to the sluggish attitude towards this technologies due to the potential loss of employment reducing strength of mine unions. Lack of stimulation by the government create a loss of opportunity for the country where benefit associated with digital transformation.

It is the view of the respondents that the technologies offer excellent solutions, which can deal with legacies of safety costs, poor productivity and efficiencies, which makes the industry uncompetitive. Therefore to realise benefits resulting from implementation of these technologies will require direct and target initiatives to deal with this factors.

5.4 Discussion pertaining proposition 3

Strategy decisions will drive sustainability and secure future of SA mining industry by using AI, ML and AT

Two emerging themes from this study to further derive insight for proposition 3 are sustainability and industry development. Encapsulating theory of TOC, with its cross section view of the organisation which include not only identifying

constraints but also their causal link, it then create an environment where strategic decisions can be pursued which will then lead to sustainability.

5.4.1 Sustainability

For the industry to succeed and prosper it requires recognition of its unique contribution to the economies globally in sectors such as manufacturing, energy, health, and agriculture. There is no doubt that the industry is facing challenges but at the same time it cannot be left to fail. It could be turned around with intervention by leaders of the industry. From the studies there are elements which support motivation for this industry to be resurrected which include strategy formulation already address above. Definition of AI, ML, and BD and AT are addressed in Section 2.5. Definitions were further used as a baseline in comprehension for purposes of seeking common understanding of this concepts for the purposes of the study. Responded understand these concepts. For the purposes of this study, the fields refers to uses and application of AI, ML, and BD and AT.

Therefore, the elements are summarised as follows:

- **Application** – refers to uses of this technologies in the mining industry resulting from the study. Thus, use were found to be in the following areas:
    - AI used in production to improve and impact production and safety.
    - These functions encapsulate AI (Digitalised reporting, environmental monitoring, training), ML and BD (predictive maintenance, Planning and ore body modelling), and AT (Drilling and Trucking).
    - AT (Remote mining), BD/AI (data management, real time data management), AT (unmanned technology, extraction from dangerous areas)
    - AT (remote drilling and trucking), BD/AI (Data harvesting and insights).

- AI, ML and AT can be introduced in ore transport, Reporting, Data analytics, Mine, Processing plant and Production cycle (Cleaning, Drilling and blast, loading, ore transport), which is expansive.
- Areas of AI, ML and AT can be employed in exploration, environmental management, consumables and ventilation which will be driven by demand'
- AI/BD (processing plant, Maintenance, Seismicity, real time monitoring, decisions), AI (utility services management), AT (production with less people)

The respondents concurs with that application and use of AI, ML and AT can strongly influence the trajectory and contribute to sustainability of the operations.

- **Benefits and Drivers** - Benefits and advantages will make the industry competitive and sustainable. Consequently, it is not surprising to observe the following list of benefit and drives for these technologies:
  - Safety – is major concern and a bad legacy for the mining industry with recorded fatalities, injuries and damage to equipment which not only impact heavily on people but also production, costs, and poor efficiencies.

    A study by Green et al. (2010), found that that lives can be saved by using robots to do entry examination before miners start their shifts, in the process dealing with issues of cost and stoppages.
  - The use of and management using AI and AT technologies can remove people from dangerous working places.
  - Minimise exposure of exposure to dangerous gases with AI monitoring sensors in working areas.
  - In response to DMR prescribe, AI driven PDS and VDS are already in place to prevent dangerous interface between people and vehicles in the process preventing harm to people and or damage to equipment.
  - New business development areas which are seen as unsafe and dangerous, can be mined with AT, especially pillars and other

deeper virgin ground, which is unknown but could have safety consequences. This will unlock additional value to the business and increase life of a mine.

- Improved production, productivity and efficiencies as driven by functions of AI, ML and AT in the production environment.
- Increased time efficiency with continuous uninterrupted cycle in the production environment through use automated equipment.
- Improved reliability with AI driven by predictive maintenance.
- Mining production to be homogenous contributing to better efficiencies in the production and processing plants.
- High equipment utilisation, improved accuracies, better quality produced with less.
- Utility on demand services mantra for management of water, ventilation and electricity.
- Shorter payback period with more value realised in short period of time due to continuous operations and increased efficiencies which will ensure investor confidence.
- Remote operation will induce skills transfer from various site where this is centralised.
- Lower cost of operations driven by efficiencies from AI, ML, BD and ML.
- Using AI for procurement process to ensure seamless operation in acquiring data and dispensing functions of invoicing, payment and acquisition of products required to support the business. This include the interface with engineering, like predictive maintenance.

- **People** – will impacted both negative and positively in application of this technologies. However people employed in the environment driven by technologies will have benefit which in the main will contribute to social economic benefits. The benefit include the following:
  - Better pay which will narrow employment inequality gaps.

  - Improved workplace diversity where cognitive strength is utilised, rather than physical jobs which can be done by males.
  - Technology will be equaliser in the workplace with minimum disparities in pay between employees.
  - Jobs will be meaningful.
- **Engineering -** is responsible for utility services and equipment utilisation which include maintenance. Application of this technologies will improve and create the following benefits:
  - Predictive maintenance instantly improves in machine availability for production.
  - Less waste in the system as parts will be ordered when required based on real data.
  - Utility services efficiencies, which will be dispensed appropriate when required.
  - Waste of utility services like water and ventilation will be acted upon immediately, with improved real life monitoring.
  - Real time monitoring and appropriate responses.
- **Mine Planning -** informs business plans which guide business navigation.
  - AI, ML and BG applied to plan ore bodies will create better life of mine plans based on real data, which will contribute to business strategy goals of safety, profitability, and sustainability.
  - ML and BG has a potential to contribute to solutions towards seismicity, which is responsible for tremors that contribute to fall of ground in underground mines, resulting in fatalities, injuries and damage to property.
  - Better plans achieved using of AI and BD to anticipate change in grade distribution.
  - Digitalised reporting will improving on how data is received and compiled to ensure various benefits.
  - Quality decisions based on good information driven by AI, ML and BG,
  - Improved business insight for short- and long-term planning.

Benefit and drivers are real and would impact positively on the success of the business in the process ensure its sustainability.

- **Impact area** - this area identified by respondents which can be impacted by these technologies of AI, ML, BD and AT in their operation and the industry. These areas include:
    - Production life cycle, mine planning, and engineering, especially maintenance, security, and management of consumables.
    - Areas that expose people to noise and dust are critical to ensure safety.
    - Dangerous working areas like deep mines, mine pillars will contribute to business without harming people.
    - Both surface and unground mines can benefit from this technology as per own requirement.
    - There is opportunism for AT in ore trucking and locos underground.
    - The old narrow reef technology equipment and processing plant is another area of impact.
    - Processing plants are mostly ideal as they are static like manufacturing plants.

Impact areas are vast along the business value chain, which offers an opportunity for intervention of employing a combination of this technologies. However there is a need for each area to establish their own areas, which can be impacted by the technology in order to advance goals of the organisations.

There are notable successes in other countries, where this technologies has been implemented in the process contributing to safety, cost, and efficiencies. A study by Lottermoser and Barnewold (2020) found that Éléonore Gold Mine in Canada installed an IoT system monitoring system, which reduced energy costs by more than $2 million per year. Another example is the investment into autonomous trucks at an open pit mine in Western Australia, which contributes to continuous production and efficiencies. In another study done by Li and Zhan (2018), autonomous intelligent driving improved effectiveness of mining equipment,

intelligent monitoring of mining processes, improved efficiency, reduction of mining cost, and improving the competitive ability of mining enterprises and safety due to intelligent mining.

A study by Reid, Ralston, Dunn and Hargrave (2011) also indicate success in automation capability in road development contributing to a safer and more productive working environment, and Zelinska's (2020) findings indicated the possibility of applying machine learning algorithms for purposes of enhancing efficiency in the mines.

A South African study by Grobler (2010) concludes that autonomous vehicles were successfully implemented in a production loop in an underground mine some 10 years ago. This the only notable project which resemble the closes known application of this technology in the country.

It is encouraging to recognise that there are successful projects overseen although in the main they are not in the majority. Somewhat more will be required to change the course in the process changing the course of the industry to greater heights.

5.4.2 Industry development

It is essential that the industry is supported so as to ensure challenges associated with issues of safety, dangerous mining areas, and mining technology limitations, especially where virgin and deeper resources and left out, pillars pose a risk to people. Challenges of primitive processes and old technologies especially in antiquated also will require a closer consideration. There is doubt that the industry is regressing looking at the following statistics. According to Langenhoven (2018), Mining in SA contribution to GDP in 1980 was 20% which dropped to 7, 3% (2018). With employment, industry employed 780k people in 1987 but this has since dropped to 456,4k by 2018 (StatsSA, 2018), with a 41% drop in the last three decade. If this trajectory continues, the industry will cease to exist and create dependency somewhere else.

In the literature, there is limited data to support industry development. However, a study by Grobler (2010), found that forming a partnership with the OEM paramount in their implementation of AT ensure success of the project. This study correlates findings of this study with respondents agreeing that collaborative effort is necessary. However collaboration in the study include miners, government, and unions in order to support initiative to revive the industry and make it more attractive. In some areas, equipment will require complete overhaul or building of newer once which are geared for this technologies tasks, making early solicitation of partnership with OEM an absolute necessity to meet industry needs.

The study also found that issues of poor safety and poor efficiencies created a bad image for the industry. It is therefore necessary to drive a change of perception in mining by adopting technologies which will contribute to better and safe mining condition. Technologies like AT will immediately moving miners into air conditioned control rooms producing away from harm's way in the process making sure effort is replaced by cognitive ability. This intervention will result in increased workplace diversity, development of better skills and payment grades will be better.

Technology is considered expensive, where a holistic approach is necessary to create capacity for skills, drive prices down to acceptable levels, and increase user scope of the technologies along the industry value chain.

The study also indicate that, education and school curriculum must be changed so as to support this technologies and develop foundation skills development at early age. Government is paramount, and must play a stimulating role. The impact of job losses is real, however with government participation other industries like agriculture can be activated to ensure employment of the country is not impacted on the macro level.

5.5 Conclusion

The mining industry carries a legacy of decline whilst there technological development that can impact operations in a positive way, changing the current downward spiral. Appropriate strategy is integral in pursuing solution found in AI, ML, and AT. This must be driven by identification of specific challenges, which can be addressed by employment of this technologies so as to ensure realisation of the company goals.

Beside evidence of negative legacies of safety, poor productivity and efficiencies and positives afforded by AI, Ml and AT to deal with this challenges, poor uptake shows that leaders are hesitant in pushing for adaptation of this technologies. Leaders are seen to be drives of the strategy through implementation of appropriate technologies to advance aspirations and goals of the organisation. It is important for leadership to take a political view to address the challenges. Skills development and seeking knowledge from comparatives industries where some of this technologies are employed. Government was found to be wanting, providing a distinct lack of support to industry. The government role in stimulating the industry is paramount not only in digital transformation, but also in stimulating other industries like agriculture, to minimise impact of potential job losses.

There is no doubt that adaptation of the digital technologies has been sluggish in the industry, however this is with justifiable due to inhibiting challenges. To be able to realise the benefit associated with these technologies, targeted initiatives must be driven so as to address this hurdles. The mining industry is important to global economies, and as a result, it can be allowed to fail. Its challenges are making it less attractive to investors. However, digital transformation through use of AI, ML and AT are expected to give a lifeline to the industry. Areas of application, uses, benefit, and impact have been identified to support improvement of legacy challenges in the process contributing to its sustainability. There is also a scope to learn internationally as there is evidence of companies, which have adopted some of this technologies in the process achieving significant cost reduction, improving on production and efficiencies.

Industry must also take opportunities to develop on macro level soliciting corroborative partnership with key stakeholders of employees, union and government to advance adoption of technologies intended to improve the operation to deal with things life safety of employees for example. TOC is proven to be a versatile tool which is holistic and can be adopted in various parts of the business and can drive elimination of constraints while driving strategy decisions.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

In this chapter, presentation of the conclusion is derived from the research questions and recommendations are then made, including suggestions for future research.

The aim of the study was to establish use of Artificial Intelligence, Machine Learning, and Autonomous Technologies in Mining Industry, South Africa. Its impact on people, production, impact areas, and its challenges and hurdles of implementing this technologies.

The use of AI, ML and AT has been found to offer benefits which can change the fortunes of the mining industry in SA. Although there is interest, implementation of the technologies if found to be lacking. There is evidence of success especially in industries like manufacturing and some spikes of success in international organisation. However, evidence from the study indicate sluggish adaption approach to this technologies. There is no extant literature to assess this phenomena and possible solutions. The study however has tried to seek deeper insight to further gain deeper insights.

- Conclusions regarding research Question 1: What are the long-term strategic decisions being made in support of AI, ML and AT?

  The evidence is clear that without intervention by AI, ML and AT in dealing effectively with legacy issues of safety, productivity, and efficiencies the industry will continue to spiral down in SA. The evidence indicates dwindling employment figures, which have dropped by more than 40% in the past three decades, and contribution to GPD in SA has also dropped by 13% in the same timeframe. To arrest this decline further, a holistic approach of embracing technology is found to be essential and upon

identifying specific challenges, leaders should design strategies incorporating digital technologies to achieve company goals.

- Conclusions regarding research Question 2: How do the implementation of these technologies affect the workforce demographics, worker relations and availability of jobs?

  Implementation of this technologies are expected to impact positively and negatively on employment opportunities. The negativity, which is loss of jobs, has far reaching consequences as it will make worse the socio-economic problems found in SA. The study indicate concerns of ethical dilemma, where the benefits of technologies are pursued at the cost of people and loss of employment. There is some pocket of the study which found that there is a possibility to minimise job losses by things like reskilling and stimulation of other industries like agriculture in mining communities. However, this will be difficult to achieve.

  The skills required for AI, ML and AT are higher and require far higher cognitive ability in the industry filled with non-skilled and illiterate working force. Using other industries especially agriculture as a conduit for those impacted and without government involvement does not offer any hope. Therefore reskilling as an option in this context is found not to be unrealistic. Where there is positive impact, it is expected that workforce demographics and worker relations will improve. Intervention of the technologies especially of AI and AT will move employees from dangerous condition to air conditions control rooms. Higher skills will attract better salaries and strength will be replaced by cognitive ability in the process contributing to increased job diversity and better relations.

- Conclusions regarding research Question 3: What are main hurdles and challenges in implementing these technologies?

  There is no doubt that evidence suggest challenges have contributed to poor adaptation of technologies, which inhibits its progress and success of the industry. Some of the major hurdles include ethical consideration where job losses is a reality, adopting technologies on antiquated mines which will require a total change in processes, high capital requirement, supporting Infrastructure, Variability is a problem even with same classes of mines, skills shortages and challenges of major stakeholders like - employees, unions and government. Therefore it is imperative to seek targeted initiatives and solutions to render this challenges inert. Options in this regard include localisation of manufacturing, acceleration of skills development, and collaboration, especially amongst major stakeholders.

- Conclusions regarding research question 4: What are the potential uses of AI, ML and AT in mining industry?
  The study has shown there are many areas along the value chain where technologies can be employed to eradicate bad legacies of the industry which has rendered the industry uncompetitive. The designed processes which are inefficient, costly, and an unsafe have shown to impact on people and the business. Therefore, is imperative for the organisations to pursue TOC to identify areas which can employ AI, ML and AT. Where there is a risk of rock burst for example, use of AT will be most effective to remove people from exposure to harm.

- Conclusions regarding research Question 5: What are major impacts areas of implementing these technologies?
  Impact areas are identified by the study and found to be those that has demonstrated poor weakling in the system by performance which inhibit attainment of company goals. The process inefficiencies, poor productivity and poor safety statistics are some of areas the study has identified.

A concerted effort is required to learn from the other successes of adaption in the industry where they technologies have been implement and or parallel industries to seek solution for own environment.

- Conclusions regarding research Question 6: How do you see the AI, ML and AT technologies changing the future of mining organisations in South Africa?

  The evidence indicate that there are benefits associated which this technologies. There is evidence of successful implementation of this technologies internationally and other industries where things like IoT and or application of AT for example has proven to contribute to improved costs savings, safety and improvement on efficiencies. Therefore supporting strategies are required to pursue local manufacturing, develop skills and creation of corroborative approach with OEM to ensure that equipment development supporting AI, ML and AT are accelerated and supported. There is no doubt that the future of the industry will be competitive should adoption of AI, ML and AT be pursued with rigor as this will ensure necessary investment which will propel the industry forward.

6.2 Recommendations

It has been established by the study that mining operation have different inherent challenges, even operations within same classes are shown to have some distinction and also different set of challenges. Therefore, a blanket approach will not be suitable to derive result-oriented intervention to seek sustainable solutions. As a result, TOC approach will be able to create focus of weakest links for elimination and ensure realignment with solutions driven by AI, ML and AT to achieve organisational goals. The benefit of TOC process is extensive and is a continual process which makes it a suitable management tool to effect change not only in systems and strategy development but input into implementation. The intention of the TOC is to remove all weaklings which stagnate the processes.

6.3 Academia

This study has proven to be significant with deeper insights into use of AI, ML and AT in the mining industry in SA context. The study further highlight areas of implementation and perceived benefit for specific mining environment either on surface and or underground. In terms of academic knowledge, the study contribute to management strategies, target areas for use of these technologies and consideration of adoption of advanced technologies during feasibility studies. The study set foundation for future research on the individual subject of either AI, ML and AT for specific application.

6.4 Suggestions for further research

The following areas emerging from the study are found to warrant further investigation through research.

- How to pursue digital transformation especially in class 5 mines, which are old, labour intensive and with complex ore bodies with minimal impact on job opportunities.
- Infrastructure challenges impede acceleration of the digital transformation. Issues of costs and poor central leadership especially from government are found to be sluggish. Therefore, amongst the organisations, the strategic imperative that must be pursued to collaborate and stimulate local manufacturing, which can influence long term costs.
- How can government be influenced to develop policy and digital transformation strategies in the country in the process revitalises the mining industry, which has been proven to be a stimulant for growth.
- How can skills deficit be accelerated to support digital transformation initiatives in the mining industry.
- To further investigate stimulation of other industries to support job creation in order to deal with deteriorating socio-economic issues and employment paradigms.
- A case study framework using TOC as a motivation for implementation of AT where fatalities could be eliminated in a mining operation.

- A case exist for determining value streams within both micro and macro environment through application of AI, ML and AT in both classes of mines

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APPENDIX A INSTRUMENTS

SECTION 1: PARTICIPANT BACKGROUND INFORMATION

Details:

Company Name				
Mine Type		**Depth**	**Commodities**	**Mining method**
Surface				
Underground				

Summary of Experience:

Age and Gender

Years Range	20 - 25	25 - 30	30 - 40	40-50	60 - 65	65 plus
Age Range						
Gender						
Male						
Female						

Qualification and Experience

Qualification	Field of Study
Below Matric	
Matric	
Certificate	
Diploma	
Bachelor's Degree	
Honours Degree	
Master's Degree	
Doctoral Degree	
Experience	**Total Years**
Current Position	
Current Company	
Industry Experience	

Position, Position Name, Department and Race

Position	Position Name	Department	Levels to CEO/Director	Race
Executive				
Senior Management				
Middle Management				
Junior Management				
Professional				

SECTION 2A: ARTIFICIAL INTELLIGENCE (AI), MACHINE LEARNING (ML) AND AUTONOMOUS TECHNOLOGIES (AT)

What are the potential uses of AI and autonomous technologies in mining industry?

- ◊ What is the best way of describing AI and its potential uses in mining industry?
- ◊ What is the best way of describing the autonomous technologies and its potential uses in your mine and the mining industry?
- ◊ In your operation and or experience what are the technologies used in the mines which can be classified as AI, ML and or ML?

What are some major impacts areas of implementing these technologies?

- ◊ What areas in your mine and or operation can be impacted by implementation of these technologies?
- ◊ Why do you think those areas can be impacted by implementation of this technologies?
- ◊ How would you describe major benefits and outcomes expected from the technologies in impacted areas in your operation?

How can mining companies utilize machine-generated big data in their Operations?

- ◊ What is the best way of describing Machine learning and its potential uses in mining industry?
- ◊ What characterises machine data and how is it different from human generated data?
- ◊ How can mining companies generate value in their operational processes?
- ◊ How can operational processes be optimised by machine data and what are the possible complications and disadvantages?

SECTION 2B: APPLICATION AND IMPLEMENTATION

What are main hurdles and challenges in implementing these technologies?

- ◊ What scope exists for the application of this Technologies as the primary means of production in South African Mines?
- ◊ What is the management approach to support strategic changes in implementation of technology?
- ◊ What is the way forward and how to successfully implement autonomous technologies in the mining industry?
- ◊ Technologies of AI, ML and AT have recorded benefits of efficiency, cost reduction, safety and increase in production and productivity. How could they contribute to challenges at your mine?
- ◊ What technologies has the organisation adopted in response to challenges of productivity and safety?
- ◊ What plans exists within your organisation in ensuring adaptation of new technology and sustainability
- ◊ Decreasing grade, depth, cost and ageing miners are some of the variables that affect mining in general. What will be your sustainable approach in dealing with this challenges using this technologies?
- ◊ How would you describe issues of labour, stakeholders and government as a potential deterrent of technology implementation?
- ◊ How would you address stakeholders to ensure application and implementation of this technologies?
- ◊ How would the environment impact on adoption and implementation of these technology?

THEME 2C: DEMOGRAPHICS, RELATIONS, SAFETY AND EMPLOYMENT

How do the implementation of these technologies affect the workforce demographics, worker relations and availability of jobs?

- ◊ What is your impression of workplace demographic on application of this technologies?
- ◊ How do you see this technologies affecting worker relations?
- ◊ How do you see this Technology impacting on safety of people in production environment on the mines?
- ◊ What technologies will the company adopt to improve on safety?
- ◊ In the advent of COVID-19 pandemic, other pandemics and risks of mining environment due to depth. What will be your approach to deal with this challenges in ensure sustainability of the operation?
- ◊ There is narrative that technology results in loss of jobs. How would you maximise job creation using this technologies?
- ◊ Where jobs are impacted severely, what would you do to ensure sustainability of impacted communities or countries of operation?

CONCLUDING QUESTIONS

- ◊ What are the long term strategic decisions being made in support of AI, ML and AT as a result of issues experienced in the industry and particular your mine?
- ◊ How do you see the AI, ML and AT technologies changing the future of mining organisations in South Africa and including your operation?
- ◊ Is there anything that I did not ask you that you would like to share?

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APPENDIX B CONSENT FORM

Title of Research: Use of Artificial Intelligence, Machine Learning and Autonomous Technologies in Mining Industry, South Africa

Name of Researcher: Setshaba Nong
Program: Masters of Management in Digital Business

I…….. Agree to participate in this research for academic purposes. The research has been explained to me and I understand what my participation will involve. I agree to the following:

(Please circle the relevant options below).

I agree that my participation will remain anonymous.	YES	NO
I agree that the researcher may use anonymous quotes in his research report.	YES	NO
I agree that the interview may be audio recorded.	YES	NO
I agree that the information I provide may be used anonymously after this project has ended, for academic purposes by other researchers, subject to their own ethics clearance being obtained.	YES	NO

Name:

Signature:

Date:

APPENDIX C CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF GRADUATE SCHOOL OF BUSINESS ADMINISTRATION ETHICS COMMITTEE CONSTITUTED UNDER THE UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: WBS/BA0502108n/711**
PROJECT TITLE	The Use of Artificial Intelligence, Machine Learning and Autonoumos Technologies in South African
INVESTIGATOR	Mr Setshaba Nong
SCHOOL/DEPARTMENT OF INVESTIGATOR	MM (Digital Business)
DATE CONSIDERED	09 October 2020
DECISION OF THE COMMITTEE	Approved unconditionally
RISK LEVEL	MINIMAL RISK
EXPIRY DATE	30 JUNE 2021

ISSUE DATE OF CERTIFICATE 23 October 2020 **CHAIRPERSON** _____
(Dr MDJ Matshabaphala)

cc: Supervisor: Dr. Sethibe

DECLARATION OF INVESTIGATOR

To be completed in duplicate and **ONE COPY** returned to the Chairperson of the School/Department ethics committee.

I fully understand the conditions under which I am are authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

Signature _____ **Date** 24/10/2020

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

APPENDIX D INTERVIEW SCHEDULE

Interview Schedule	
Respondent	**Date of Interview**
Respondent 1	26/11/2020
Respondent 2	26/11/2020
Respondent 3	02/12/2020
Respondent 4	20/12/2020
Respondent 5	22/11/2020
Respondent 6	02/12/2020
Respondent 7	02/12/2020
Respondent 8	09/12/2020
Respondent 9	09/12/2020
Respondent 10	10/12/2020
Respondent 11	15/01/2021
Respondent 12	15/12/2020
Respondent 13	20/02/2021
Respondent 14	27/01/2021

APPEDINX E: THEORY OF CONSTRAINSTS TAILORED MODEL

