The Application of Robotics in Deep Level Mining in South Africa and its Influence on Health and Safety.

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ABSTRACT

Application of robotics in mining operations particularly in deep mining is considered to be challenging when factoring the impact of health and safety in day to day operations. Majority of the employees in South Africa's mining industry have low training levels, unskilled work content as well as large figures of underground employees labouring for survival at lower-end cost curves and excessive exposure to deprived underground conditions. The rising demand for mineral products is compelling mining companies to go deeper in mines even where such increase in the depth results in higher costs, risks, and a further decline in the conditions of working. This paper examines the current application of robotics in deep level mining, discusses the challenges in robotics adoption and their influence in health and safety. Trusting on the qualitative content analysis methodology the study adopted to interview participants and collect data from the mining journals for sampling and data collection. The findings suggest that although deep-level mines have embraced an increase in robotics and extensive methods due to global competition and the need for better access to mineral reserves trends in productivity in the gold mining industry remains unchanged for a long period and mining labour remains impacted by slow technological advancement. Inadequate application of robotics and developed control policies and measures for dealing with occurring mining disasters are some of the key challenges with the robotics adoption. The application of robotics will allow all safety experts to plan for exploration, extraction, optimisation of operations and worker monitoring as well as protection. The limitations of the study is that there are few current publications peer reviewed articles and the prevailing literature is old for the current research. The study concludes that there is a gradual advancement of technical capacities in deep-level mining. The main technical challenges to the application of robotics is the availability, reliability as well as fail-safe operations of robotics. Lastly robotics will improve exploration, mapping of mining operations as well as worker equipment. The study recommends future studies on comprehensive approaches to the socio-economic effect of robotics mechanisation and application in deep-level mining.

KEYWORDS.

Application of robotics, qualitative content analysis, Literature review, deep-level mining, South Africa, Challenges, impact on health and safety.

DECLARATION

I, Tebogo Gaokgorwe, declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in the field of Digital Business at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Name: Tebogo Gaokgorwe Signature: Tebogo Gaokgorwe

Signed at: Alberton……………………………………………………

On the 16th ……………………………. day of June………………………… 2023

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LIST OF ACRONYMS

Research & Development (R&D)

United Nations Conventions of the Law of the Sea (UNCLOS)

International Labour Organisation (ILO)

Southern African Development Community (SADC)

Tuberculosis (TB)

Mine Health and Safety Inspectorate (MHSI)

Health and Safety Executive (HSE)

Occupational Health and Safety (OHS)

Shearer Position Measurement System (SPMS)

Load Haul and Dump (LHD)

Honeywell Ore Recovery and Tunnelling Aid (HORTA)

Instant Scene Modeler (ISM)

Remote Operated Vehicle (ROV)

Deep Sea Mining (DSM)

Personal Protective Equipment (PPE)

Best Environmental Practice (BEP)

Good Industry Practice (GIP)

CHAPTER ONE: INTRODUCTION

1.1 PURPOSE OF THE STUDY

The purpose of this study is to conduct a qualitative investigation into the adoption of robotic technology and its influence on health and safety measures on deep level mining in South Africa's mining industry.

1.2 CONTEXT OF THE STUDY

1.2.1 Global Mining Industry

International mining sector faces immense burden following declining financial conditions and the demand for essential resources due to the slowing-down in the growth of China accompanied by unpredictable drop in product prices (Bertayeva, Panaedova, Natocheeva & Belyanchikova, 2019). The global mining industry continues to face numerous challenges like low monetary conditions, environmental conditions and legislation compliance, changes in operation occasioned by the maturity of prevailing operations as well as stakeholder mismanagement (Mavroudis & Pierburg, 2017). The declining resource quality or grade, the overall performance of the sector and necessity to advance health and safety conditions continue to challenge the international mining industry (State of Play, 2018). These growing challenges have resulted in advanced costs of production, lower revenue generation, lower profit margins as well as a decline in return on investment.

These challenges place growing pressure on mining institutions internationally to put more effort into efficiency, safety and shareholder profitability. In addition, the global mining sector faces volatile and unpredictable product charges, which have caused investors to put advanced risk premium on mining stocks. Stakeholders, therefore, continue to request for the delivery of improved value by the mining institutions across all the commodities varieties despite the existing state of a frail economic performance internationally and the industry's deepest performance (Zimroz, Hutter, Mistry, Stefaniak, Walas & Wodecki, 2019). The next section looks at the South African Mining industry.

1.2.2 South African Mining Industry

In addition to international pressure, mining operations in South Africa also face numerous resident challenges that continue to exacerbate their position if compared to international mining institutions. The uniqueness of the multifaceted challenges South Africa's mining sector faces includes labour unrests, ambiguous regulatory or governance environment, the rising government demands, issues of low energy reliability and margins (De Graaf & Spiteri, 2018). The Minerals Council South Africa (2020) reports that South Africa's labour market continues to register extremely unionised personnel, with the labour unions possessing a huge bargaining power due to member number. South Africa's mining industry has a yearly season of wage negotiation, habituated with numerous strikes which paralyse the sector and results in production loses. Consequently, the companies in mining settle on increases in inflation in the effort to control the labour strikes. The low-profit margins arise as a result of the high costs of input occasioned by the falling international commodity prices, high rate of exchange, increases in energy and costs of labour that continue to rise above the rate of inflation.

Mining companies in South Africa experience constant pressure from the national and local governments to increase social resource commitments and provide for the services which generally form part of government obligations, for instance access to basic human services, healthcare and education for native mining communities (Macmillan, 2017). The prospects of local societies or communities to contemporary healthcare access, skills development as well as job opportunities exacerbate further the pressure. Various factors have resulted in higher costs of production and work losses since they damagingly impact the viability of the mining business and operators . South African's mining industry, therefore, faces a decline due to the effect of added pressures; if compared to their international counterparts, these factors above are causing increasing pressures for mining establishments. The International Labour Organization indicates that proof of the decline is due to the international mining organisations existing in South Africa as well as vast shedding of jobs in 2016 since mining firms struggled with profit (ILO, 2020).

1.2.3 Technology in South Africa's Mining Industry

Technology is recognized widely as playing a vital role in the application and development of mining approaches; eventually improving both health and safety as well as the operational effectiveness of South Africa's mines (Sutherland, 2020). The successful management of mines requires the establishment of systematic administrative processes and programmes that permit the technology and its methods to be effectively and sustainably implemented. The processes are dependent on the execution of the change management ideologies as well as systems engineering approaches to the prevailing problem (Campbell, 2018). Miners and their administration need a complete understanding of change aspects and their impact on new technologies. In regard to the South African industry, the impact of technology recoveries is a 1% improvement in concentrator-extraction efficiency or mining, that is, R500 million at current prices in yearly revenue. The current extractions from the Situ reserves to the smelter feed have risen to a paltry 80% (Minerals Council South Africa, 2020). Therefore, a R10 billion per annum industry lead awaits the technical innovations (Statistics South Africa, 2020).

1.2.3.1 Tripartite Action Plan

In the year 2008, the leaders of South Africa's mining industry consented to a Tripartite Action Plan on Safety and Health aimed at reducing to international standards the rate of fatality frequency in South Africa's mines. For both non-gold and gold mines, the annual improvement and actual achievement indications were that included: a) South Africa's industry of mining is struggling to accomplish its goals on safety, and b) the safety problem is worsening in the sector of gold mining (The Mining Qualifications Authority, 2020). Other than the issue of safety, the mines in South Africa, specifically the gold mines, possess more hostile conditions of working. The deep-mine conditions in South Africa are the severest in the whole world with narrow stopes, cruelly confined areas of working, long face trips, extreme humidity and heat and with less than required manual labour amounts. For companies and miners to fit existing machinery and humans into such areas of work, the miners must dig up more rocks than the anticipated layers of soil bearing (Jones, Sofonia, Canales, Hrabar & Kendoul, 2020). The costs of such constraints are resulting in cut-off reef breadths, smaller than which cannot be cautiously and financially mined.

1.2.4 Robotic Technologies

While spiralling energy and labour costs continue to put pressure on the monetary performance of the mines in South Africa, the solution is in the adopting of robotic technologies A majority of the robotic technological solutions to mining are around mechanization, enabled by numerous technologies convergence, from robotics to artificial intelligence (Mining Indaba, 2019). By executing automation, South African operators protect underground miners and other employees from injury and become a huge imperative if the miners and employees are to stay or become investible by global capital. The increased stress on mine and workforce safety is the motivation for developing the mining robotics market. Previously, the old-style drilling and exploration techniques compromised the mine employee security. McKinsey's '*Putting the Shine Back on South African Mining'* report of 2019 emphasizes technology as a crucial pillar for the success of mining because it improves worker safety, visibility and performance management (Cassim et al., 2019). Mining firms can offer connected smart devices like drones that are managed by the workers to communicate actual task information, progress reports, and work plans (Jones, Sofonia, Canales, Hrabar & Kendoul, 2019). South Africa's international mining companies are issuing connected smart tablets to underground employees, to improve the productivity of the firm by ten (10%) per cent. A constant introduction of the remote centres of operation to manage and track automated drill performance is improving safety and performance as well as reducing the downtime.

1.2.4.1 Robotics and Health and Safety

The rising demand for mineral products is compelling companies to go deeper in South Africa's mines even where such increase in the depth results in higher costs, risks, and a further decline in the conditions of working. The continued use of Robotic technologies like the Nederburg miner have increased the chances of mining narrower and deep-level reefs. The concept of the Nederburg miner increases the state reserves presently excluded due to the depth (O'Connor & Sertic, 2020). This robot is intended to identify the hanging, loose rocks after blasting the rocks face in stope that would have a danger to employees (miners) coming back to the stope and remove the mineral by blasting. The robotic technologies make it possible since the loose rocks remain to some extent cooler than solid rocks around them.

An advancement of automated or robotic technologies for the mining sector significantly reduces the dangers the miners and employees face when underground. The robotic technologies considerably improve efficiency and productivity levels in the mining environment (Zhang, 2017). For instance, thermal cameras can detect small enough minerals as well as the difference in temperature or cooling. Acoustic sensors can detect adequate differences as well as the sounds by the loose rocks even though they somewhat are different from solid rocks sounds. Therefore, robotics fitted with thermal cameras, acoustic sensors and processors for miners to enter the mine stope after a robot has inspected it (Ruiz-del-Solar, Vallejos, Asenjo, Correa, Parra-Tsunekawa & Mascaro, 2016). Robotic technology innovations entail permitting the robotics application to the deep-level mine responsibilities that are extremely challenging, not safe for people, and enable the mining operations to reach the mineral deposits, which cannot be cautiously extracted using existing conventional methods or layouts of the mine. South African Companies must, as part of their mining agreement, explore applications like robotic mine equipment, mapping as well as computerized inspections (Uys & Webber-Youngman, 2019). The two leading drivers to the return of the active curiosity in the mining robotic technologies in South Africa are the public and government institutions as well as the mining industry.

On the mining industry's part as well as the public sector, the interested is entrenched in the fear of the country's hard-rock mining future. The two institutions desire to diversify and expand South Africa's mining equipment manufacturing segment and are also worried about the increasing mine safety (Jacobs & Webber-Youngman, 2017). While some of South Africa's mining corporations are, on one hand, expressing their interest in investing in mining robotics technologies, automation, research and development (R&D), the nation's government is, on the other hand, investing in Mining technology initiatives and programmes like the Operation Phakisa ('Hurry Up') programme. Operation Phakisa is a fast-results delivery programme," says its website. "Operation Phakisa is an innovative and pioneering approach to translate detailed plans into concrete results through dedicated delivery and collaboration (Macfarlane, 2018). A key element of such government initiatives is the development of partnerships between the private and public sectors as well as civil society organisations and academia.

Ralston, James and Hainsworth (2018), state that despite the clear benefits and advantages of introducing robotic technologies to South Africa's mining, the continued limited success is due to a) the change resistance in the industry; b) unreasonably complex technologies' deprived ergonomics in regards to the equipment movement out and in of the stopes; c) the Hawthorne impact because of hefty and out of balance administration push with employee change resistances; d) worries the technologies will result in job loss if combined other mechanization. Even though the trials have repeatedly been exceptionally successful, mining employees and companies have not implemented the technologies, often returning to their tried-and-trusted conventional approaches of mining. South Africa's mining employees and companies take time to accept electronic delay detonation technology (Plotnikov, Kolokoltseva, & Volkova, 2020). Management units have often considered as excessive the initially high capital cost and operating cost when compared to conventional systems.

Richard (1998), has suggested a seven-step change process for robotic technology application and introduction to South Africa's mining industry. The steps include: a) understanding the organisational culture in regards to change capability and readiness. In certain situations, change many be mandatory and not voluntary for survival; b) continuous communication with company levels affected by robotic technology implementation. Constant foremen involvement is, for instance, essential because they are the main users of the mining system; c) offer greater executive challenge by senior company management participating in practical mining, setting goals, asking the correct questions, and strictly tracking the implementation progress; d) ensure the project director and system administrators are competent to dealing with respect and authority between affected stakeholders, bridging the foremen, operators, supervisors, management, engineers amongst others; e) there is a need for change management to get different outcomes; f) commitment to technology changes and expected problems that may arise when change occurs, there is initial denial, then delayed use (Medicinal) before employee acceptance (ownership); and g) employees must understand clearly the company's vision and commercial case. This study, therefore, conducts a qualitative assessment of the possible application of robotics on deep-level mining in South Africa and its impact on health and safety.

1.3 RESEARCH PROBLEM

South Africa's mines are the most dangerous in Africa and the leading cause of death rates. The industry comprises the use of conventional approaches and tools or even small robots for operations. Majority of the employees in South Africa's mining industry have low training levels, unskilled work content as well as large figures of underground employees labouring for survival at lower-end cost curves and excessive exposure to deprived underground conditions. There is less robotics technological application or breakthrough in South Africa's mining industry despite the massive complications on which South Africa's mining industry is dependent. The mining businesses in South Africa, as well as the industry, are generally unwilling to invest in mining research. The small mining businesses lack the capacity to offer research funding because they prefer to get finished goods from abroad.

Notwithstanding the vast local capabilities in research and development, there's neglect or non-use, and lack of collaboration between manufacturers of the robotic technologies, researchers and South Africa's mining firms. The Mining stakeholders, mainly the corporations are hesitant to exchange their experiences and expertise. Manufacturers that work closely with the mining businesses are similarly hesitant to share needed information, perhaps to safeguard their mining competition. Often, it is not the technicians that resist the needed cooperation but the miners. Internationally, the standard model is collaborations between government research institutions and mining businesses to develop mutually valuable robotic technologies, Research & Development. South Africa has failed to follow suit because there is no amalgamation of procedures, technologies, and training amongst others. Majority of the failures in South Africa's mines arise out of human failures, mainly approaches to technology use, location, and time the people use them. It is not merely about robotic technologies.

The problem at hand and the research question that follows is, how can robotics technologies be applied to deep level mining in South Africa with consolations of what will be its impact on the health and safety measures in mining operations? Which framework is going to be used towards a model that will provide scientific theory to address this? The literature argues that for the deep level mining operations in South Africa to adopt mining technologies quicker, certain operations need to be optimized.

In an attempt to understand the identified problem, the study will use the systems theory to analyze what application of robotics technology can be applied and its relation to health and safety. As such, this study has conducted a qualitative assessment using exploratory content analysis of the possible application of robotics in deep-level mining in South Africa and its impact on health and safety.

1.4 RESEARCH OBJECTIVES

This study raises the research objectives below to resolve the research problem;

- To review the existing literature to determine the current application of robotics on deep level mining in South Africa;
- To identify and discuss the challenges to the application of robotics on deep level mining in South Africa and
- To examine how robotics on deep level mining may influence health and safety.

1.5 SIGNIFICANCE OF THE STUDY

The study adds to the existing literature on the possible application of robotics on deep level mining in South Africa and its impact on health and safety. For the miners and mining industry, the study may identify factors or challenges that enable or inhibit effective adoption of robotic technology in the mining industry. This study may raise possible solutions to effective adoption of technology and health and safety measures in South Africa's mining industry.

1.6 DELIMITATIONS OF THE STUDY

This study was limited to South Africa's mining industry. As such, there may not be generalizing of the study results to other parts of the African continent or world. In addition, the study was limited to the available literature particular population on mining following the Minerals Council South Africa's drive and need to encourage the modernisation of the mining sector (Minerals Council South Africa, 2020). The study, therefore, focused on the challenges to the application of robotics on deep level mining within selected mines in South Africa. At the time of conducting the interviews

COVID-19 presented many challenges with regard to access to mines and participants. Resulting in strict movement and participant reluctance to participate in the study. .

1.7 DEFINITION OF TERMS

Mining - the extraction of treasured minerals and/or other environmental resources from the Earth (Mavroudis & Pierburg, 2017).

Robotics technologies - all procedures necessary to the designing, building and maintenance of robots as well as other smart or intelligent apparatuses (Campbell, 2018).

Safety and health –the right of each person or employee to undertake their everyday work in a very safe work setting irrespective of the industry (The Mining Qualifications Authority, 2020).

1.8 ASSUMPTIONS

- The first assumption is there is less application of robotics on deep level mining in South Africa and its impact on health and safety.
- The second assumption is that there are challenges to the application of robotics on deep level mining in South Africa.
- The third assumption is there is enough literature relating to the adoption of robotics in mining to enable the study to reach it objectives.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter contains a review of current literature on the application of robotics on deep level mining in South Africa and its impact on health and safety. The first section of the chapter focuses on the current application of robotics on deep level mining in South Africa and its impact on health and safety. The second section of the chapter discusses the challenges to the application of robotics on deep level mining in South Africa. The last chapter raises the theoretical framework used for this study.

2.2 DEEP MINING

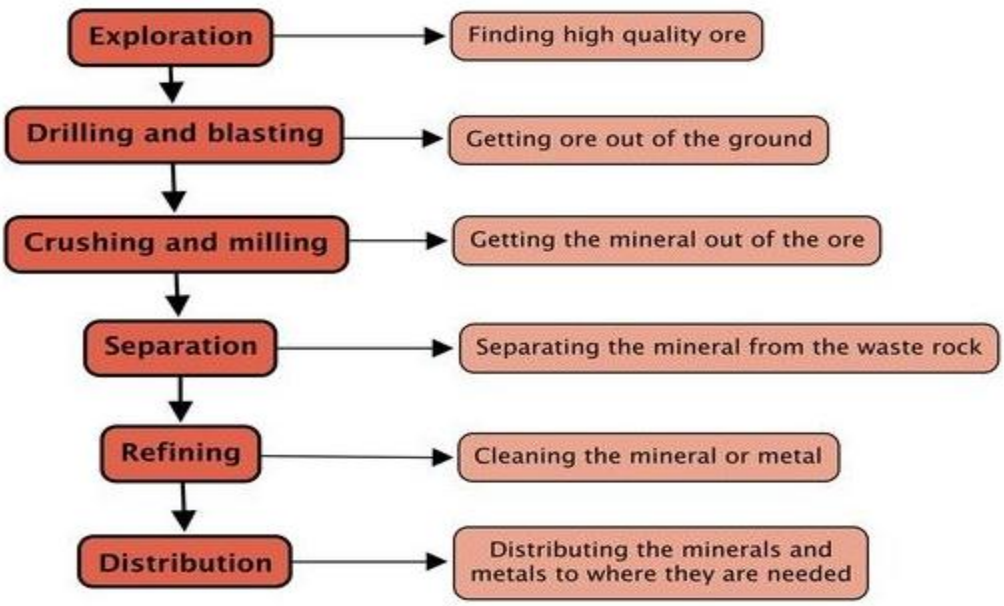
2.2.1 Definition and Nature of Deep Mining

Mining means extracting valuable reserves and/or other geographical resources from the Ground. The main purpose of the mining process is to offer a society or community the products and minerals that are needed for production of energy, delivery of needed materials for the construction, pharmaceutical, food, chemical and manufacturing industries (Wagner, 2019). The leading techniques of mining are underground (sub-surface) mining and surface mining (Newman, Agioutantis & Leon, 2017). While no unanimously-acknowledged definition prevails for deep mining, a majority of the prevailing definitions relate to the variations in conditions of mining and the difficulties linked to increase in the depth of mining. The leading obvious depth effects are the rise in *in situ* rock pressures that occasion damage to the excavations as well as the rock temperature increases which occasion unfavourable ecological situations and related physiological tensions for the workers (Xie, Ju, Gao, Gao, Liu, Ren & Ge, 2018).

The prevailing efforts to describe deep mining in regard to a particular value in depth have registered mixed accomplishment as the depth effect on rock pressure-related problems depends not only on the mining depth but the rock mass strength too (Sun & Xue, 2019). This measure above also applies to the mining depth effect on the heat atmosphere in the deep mines that is also dependent on the rock mass heat properties. As such, deep mining means exploitation of mineral using the underground mining methods. Mining studies define deep to mean 1.5 kilometres (5000 feet) and more, wherein there are high stresses to result in sloughing of development openings, not to mention walls and faces in stopes (Song, Chugh & Wang, 2017). Nevertheless, deep conditions may prevail at less depths where the tectonic horizontal pressures are greater than the gravitational pressures.

According to Zong, Kim, Ngo and Harismendy (2017), the process of mining commences when mining companies explore, identify and assess if a mineral deposit is financially worthwhile. The mining companies then develop the needed infrastructure to prepare and reach the mine for selection, extraction and transportation of the identified mineral. For deep mining, the selection, extraction and transportation usually need shaft equipping and sinking, tunnel development from the shaft to the deposit's vicinity (primary development) as well as inside or close the deposit of minerals for extraction preparation (secondary development). The selection, extraction and transportation in deep mining also needs vertical infrastructure development in the area of extraction to enable mineral ventilation and transport, that is, ventilation shafts or ore passes (Tokarz, Grabowski & Nowak, 2018). The comprehensive layout is dependent on the used geometry of local geology, extraction system and mineral body. Extraction system means the stoping arrangement as well as extraction stope excavations (Sanmiquel, Bascompta, Rossell, Anticoi & Guash, 2018). The nature and geometry of the mine, the situation of pre-mining rock pressure, mines mechanical properties, as well as the production and country rock levels determine the arrangement of stoping (De Santis, Contrucci, Kinscher, Bernard, Renaud & Gunzburger, 2019).

Figure 2.1: Mining Process



Source: (Siyavula, 2020)

2.2.2 Global perspective on Deep Mining

Prior to 1996, there were, at the least, eighty (80) mines with over 1000 meters in depth, mostly in South Africa, United States, Canada, India, Russia, Poland and Australia. Of all the top ten deepest mines in the world, six (6) are in South Africa whereas four (4) are in the US and Canada. The normal depth of South Africa's mines is 2000 meters while the TauTona (Western Deep Level) mine is 4800 meters. As of 2018, South Africa's Moab Khotsong mine stands at 1.61 million ounces (Moz). The Kidd Creek mine in Canada is the fifth (5) deepest mine and in the world, extending up to three kilometres below the earth surface. In 2018, the LaRonde mine in Canada extended its depth of mining to 3008 meters below the earth surface. South Africa's South Deep mine is the seventh (7) deepest mine worldwide, extending to 2998 meters below the earth surface and covering 4,268 hectares in area. While the Lucky Friday in United States is the eighth (8) deepest mine worldwide with a depth extending to 2.6 kilometres, Canada's Creighton mine is the ninth (9) deepest mine worldwide with a 2.42 kilometres depth of mining. South Africa's Kopanang has a depth of 1350 meters to 2240 meters. The Mponeng mine in South Africa is the world's deepest mine at about 4 kilometres beneath the surface of the earth (Mining Technology, 2020).

2.2.3 South African Perspective on Deep Mining

According to Casey (2019), South Africa began its first mine operations in 1852 as a copper project, which today is the cornerstone of the Springbokfontein town or Springbok in the Northern Cape Province. In South Africa, profitable and large-scale mining began when Erasmus Jacobs discovered diamond on the Orange River banks in the year 1867 and subsequently, the exploitation and discovery of the Kimberley pipes. Barberton and Rest's Gold rushes became the precursors of the main discoveries including the Main Reef/ on Gerhardus farm in the year 1886 as well as the subsequent fast gold field developments like Witwatersrand Gold Rush (Kamunda, Mathuthu & Madhuku, 2016). Today, Gold mining is South Africa's main deep-level mining activity that is characterised and positioned by high temperature and hard-rock mining.

Even though South Africa leads in mining products and equipment, an environment of excessive excitement prevails about new technologies that may make possible deep mining as well as prolong the mines life (Ledwaba & Nhlengetwa, 2016). The current technologies used in mining are short of the desired standards notwithstanding the huge utilization of traditional mining. As against the increasing mining difficulties like rock bursts, heat, narrow stopes and erratic grades, the prevailing mining technologies permit a twenty-five metres minimum face advance per month at the deeper level (Cairncross & Kisting, 2016). New technologies aid in the improvement of numerous hurdles that South Africa's miners face today (Macmillan, 2017). Additionally, the technology unquestionably increases the operational progress of key and/or confidently smaller mineral producers in South Africa.

Developing the technical capacities to deep-level mining has made South Africa a leader in the world in regard to deep-level mining technologies (Ledwaba, 2017). However, there is need for more utilisation of increase in depth, extensive methods of mining, exploration and technologies to attain greater access to mineral reserves. Majority of South Africa's mining companies are already mining at the deep levels that the deepening of mines increases further the life of the mine as well as cost competitiveness (Hermanus, 2017). The Major mineral producers are similarly engaged in developing robotic technologies as well as advanced methods of mining, like increased mechanisation which have applications in deep-level mining. South Africa therefore has ultra-deep pits with shafts that are deeper than three kilometres, temperature increases past fifty-five degrees Celsius as well as rock bursts (Mhlongo & Amponsah-Dacosta, 2016). The conditions of mining are posing numerous logistics, health and safety challenges.

Although innovative, the methods of mining in South Africa have largely remained unchanged in the last decade, with miners using the traditional means of re-entry and blast in mines (Neingo & Tholana, 2016). However, globalization and demand have made mines become deeper. South Africa miners are currently using five key methods of mining including: a) cut and fill; b) drift and fill; c) shrinkage and stoping; d) room and pillar; as well as e) bulk mining like block mining. Miners are also using the conventional drill and blast mining method. After the blast, the miners use the jack-legg drill to attain access to minerals, before transporting the minerals to the surface using the scaling bar (Khalifa, Gouda & Yassin, 2020).

2.3 MAIN METHODS OF DEEP MINING

The leading methods in deep mining are Open-pit, underwater, underground mining and Block caving mining.

2.3.1 Open-pit Mining

Open-pit (opencast) mining is a technique of surface mining which entails extracting the minerals from open pits in the earth. Opencast mining is the most used method worldwide because it never requires extractive tunnels or methods. The surface technique of mining is mostly used in ore deposits found comparatively near the earth's surface (Fan, Ren, Xiao & Mao, 2018). Open-pit Opencasts start from the surface of the earth, preserving exposure to the earth surface all through the period of extraction. The excavations often have step sides to guarantee the miners' safety and wide ramps where the miners can transport equipment or efficiently remove the product from the mining site (Dryzhenko, Moldabayev, Shustov, Adamchuk & Sarybayev, 2017). Mining companies practice Open-pit mining when the rock ore-bodies are huge and situated closer to the earth surface. Amongst the advantages of open cast mining are a) the possibility to use powerful shovels and trucks to move huge rock volumes; b) there are no size restrictions on equipment due to opening; c) there is quicker production; and d) low mining costs (Yakovlev, Karmaev, Bersenev, Glebov, Semenkin & Sumina, 2016).

Figure 2.2: The cycle in opencast mining

Source: (Anglo American, 2020)

2.3.2 Underwater / Deep sea Mining

Miners use underwater or deep-sea mining when the identified mineral or product is situated in a marine setting like the sea floor (IUCN, 2018). Deep-sea mining denotes the procedure of regaining minerals from the ocean's area of 200 meters, covering around 65% of the surface of the Earth. It is a unique challenge – and one that requires a responsible approach that thoughtfully considers the local ecosystem (Van Dover, Ardron, Escobar, Gianni, Gjerde, Jaeckel & Smith, 2017).

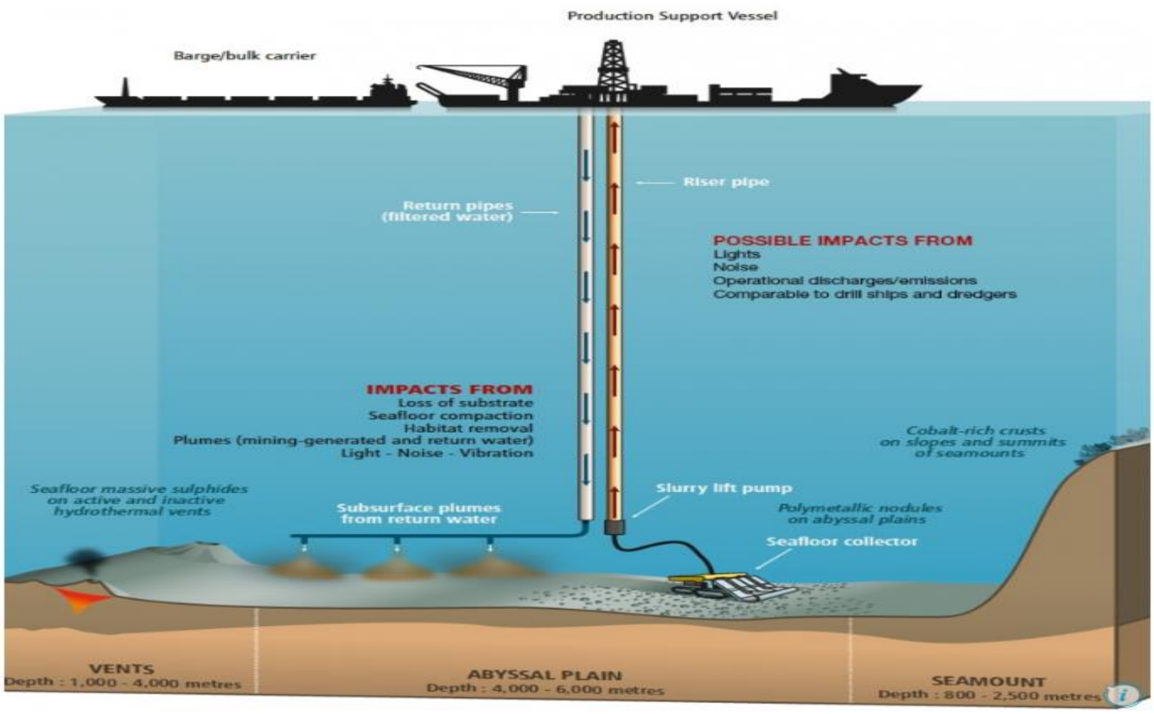


Figure 2.3: Deep-sea Mining

Source: (IUCN, 2018)

The international law on deep sea mining is the 1994 United Nations Conventions on the Law of the Sea (UNCLOS), setting up the International Seabed Authority (ISA) to regulate ventures of deep-sea mining amongst nations in the Exclusive Economic Zone, that is, 370 kilometres (200-nautical miles) off the coastal countries (United Nations, 2020). The International Seabed Authority requires countries interested in sea mining to traverse two identical sites of mining and report one to the ISA alongside a mining technology transfer of ten to twenty years (Hylton, 2020). These severe requirements have been amended because they resulted in industrialized nations refusing to sign the 1982 treaty (International Seabed Authority, 2020). Today, continuous-line bucket system (CLB) as well as the hydraulic suction systems are two principal mineral extraction types for deep-sea mining operations. The continuous-line bucket system (CLB) is the preferred nodule collection method which operates like the conveyor-belt, operating between the floor of the sea to the oceans' surface where the mining platform or ship extracts the wanted mineral and returns all the tailings to the sea (Ma, Schott & Lodewijks, 2017). Hydraulic suction mining entails lowering a pipe to the floor of the sea that transfers the knots up to the mining platform or ship. The other pipe to the floor of the sea from the ship returns tailings to the mining area per site (Zhao, Xiao, Peng & Zhang, 2018).

2.2.3 Underground Mining

Miners use underground mining to excerpt minerals economically and safely from below the earth surface with less waste (Vogt, 2016). Entry to the underground mine from the earth surface can be through vertical or horizontal tunnel, termed decline, adit or shaft. Mining companies practice Underground when: a) the mineral body is so deep to profitably mine using open casting; b) the mineral quality or grades are so high to cover the costs of mining; and c) the underground excavation has low ground footprints than the open cast mining (Ji, Eger & Dickey, 2016).

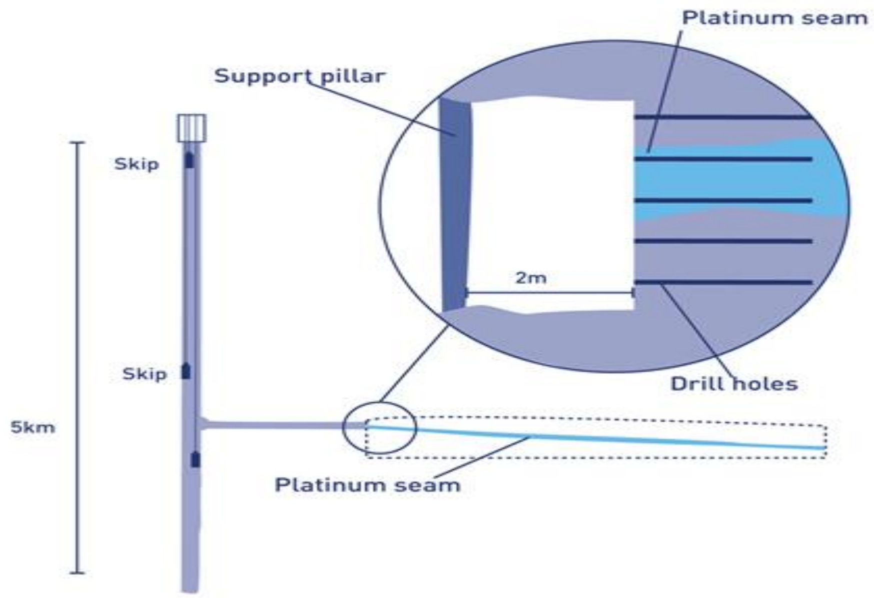


Figure 2.4: Underground mining

Source: (Anglo American, 2020)

The methods of underground mining that a majority of South African companies use comprise of a) the room and pillar; b) narrow vein stopping; as well as c) large-scale mechanised mining (Gumede, 2018). Room-and-pillar mining means the mining style where the mining companies drive the tunnels in a chess-board outline with huge square pillars standing between them that are progressively removed as the operations proceed (Chikande & Zvarivadza, 2016). Companies perform Narrow vein stopping in underground excavations alongside geological veins, that is, separate sheet-like forms of candied minerals in a rock, where there is mining and removing the mineral (Gumede, 2018). To back underground mine stoping, the mining company initiate excavations for the engine rooms as well as pump chambers and/or for purposes of access like shafts, winzes, raises and drives. Companies employ Narrow vein stopping for the mining platinum (Le Roux & Stacey, 2017). The methods of large-scale mechanised mining in South African companies comprises: a) the long-wall mining, wherein there is single-slice mining of minerals long wall, frequently by use of big machines; b) the sub-level-caving, wherein companies use explosives to blast mineral levels; and c) the block caving, wherein companies blast and extract large mineral areas with the aid of gravity (Rupprecht, 2017).

2.2.4 Cut and Fill Mining

The Cut and Fill method of mining is a short-hole mining method where companies use in abruptly irregular or dipping mineral zones, particularly where there is a limitation of the hanging wall on application of the long hole approaches (Liu, Sui & Zhao, 2017). The companies mine minerals horizontally or somewhat in an inclined slice before filling the holes with excess rock, tailings or sand. Companies can fill using concrete consolidation, or even unconsolidated. The Cut and fill mining method is a selective yet costly technique, with low mineral loss as well as dilution (Balusa & Singam, 2018).

2.2.5 Drift and Fill Mining

Similar to the cut and fill method, the Drift and Fill mining method is used in mineral zones, especially ore that are broader than the drifting method. In the Drift and Fill mining method, the companies develop the first drift in the mineral before backfilling using the consolidated fill (Ran, 2019). The companies drive the second drift together with the first drift, until there is mining in the mineral zone to its complete width and the second cut starts on top of that first cut. In the method of drift-and-fill mining, companies highly mechanise production using the long-hole stoping, wherein reef widths permit this and the long-hole stoping or cut-and-fill in slim reef regions. While Mining companies use the Drift-and-fill method of mining in the flat-lying reef regions, they handle broken minerals using the remote-directed load-haul-dump machineries (Sengani, Zvarivadza & Netshithuthuni, 2018). The depth of the mineral body denotes that there must be de-stressing all areas of stopping by creating conservative narrow-reef stopes and, backfilling the stopes upon extraction, using the surfaced mill-tailings.

2.2.6 Shrinkage and Stoping Mining

Shrinkage stoping is a short-hole mining method which is suitable for steeply dipping ore bodies (Yu, Wu, Wang & Li, 2017). The Shrinkage stoping method of mining is comparable to cut and fill method of mining. The exception is that after upon blasting, the miners leave the broken mineral in the mine’s stope where the mineral is used in supporting the nearby rock as a stage of working or operations. The companies extract adequate minerals from the stopes to permit next slice blasting and drilling (Özyurt, & Karadogan, 2020). The companies empty the stope upon blasting all the minerals. Even though the method is so selective to allow lower dilution and most of the minerals stay in the stope up until completion of mining, there is a late return on employed capital (Balusa & Gorai, 2019). In South Africa, AngloGold uses the Shrinkage and stoping in the Mponeng mine.

2.2.7 Room-and-Pillar Mining

Companies use the Room and pillar method of mining in slightly dipping-bedded or flat mineral bodies (Napa-García, Câmara & Torres, 2019). Miners leave the Pillars in regular patterns as they mine out the rooms. In numerous room-and-pillar mines, companies take out the pillars starting with the outermost point from the access to the stope, permitting roof collapsing and stope fill (Chikande & Zvarivadza, 2016). The practice permits better recovery since less minerals are left behind in the mine pillars.

2.2.8 Block Caving Mining

Block caving mining denotes a system of mining that involves the undermining of minerals and permitting it to fail on its individual heaviness, a procedure opening access to the deep deposits (Cholteeva, 2020). South African companies have recently applied the caving system of mining at a two (2) kilometre underground depth. Heights of the caving have drastically increased from 200 meters to 500 meters, generating the super caves. The challenge for the operators eager to employ the depth method is the inadequate caving experiences in such environments. As the low-grade minerals happen at the depth, the mining businesses will progressively employ the block caving system of mining to stay lucrative (Castro, Basaure, Palma & Vallejos, 2017). Additionally, companies have successfully used block caving method as a substitute for the development of fresh mines and/or extending the opencast operations. For this reason, studies have termed the block caving method as the underground form of open-cast deep mining. The other advantage of the block caving method is the great reductions in the surface excess disposal. In contrast to the open-cast mining method, the block caving method reduces the surface land impacts during which there are higher waste rock ratios to minerals (Vallejos, Basaure, Palma & Castro, 2017). The quantity of wastes rock produced from the methods of underground mining like the block caving method, with the waste in the areas of surface storage is exceptionally low.

Macfarlane & Singh (2017) state that notwithstanding the many advantages of the block caving, the method has serious considerations. For instance, there are high preliminary capital investments in using block caving mining. However, what makes the method attractive is the low operating cost. The other challenge of the block caving method is that it requires many kilometres of progress prior to production.

2.4 HEALTH AND SAFETY ON SOUTH AFRICA'S MINING

2.4.1 Health and Safety

Both in small and large-scale mining, the practice of Mining stays inherently dangerous. Miners remain exposed to several risks including injuries from: a) flooding, fires, collapse, vehicles and machinery, b) harmful material like mercury, dust and such other compounds; as well as c) deprived ventilation, overexertion and insufficient space (Amponsah-Tawiah & Mensah, 2016). There are no fatalities, serious injuries and/or life-aggressive occupational diseases that international and national institutions regard as tolerable. Miners have the right to go home safely daily, without adverse health effects (Coulson, Stewart & Saeed, 2019). The International Labour Organisation (ILO) indicates that around 40 million incidents occur at the workplace worldwide each year, 360,000 of which are fatal. There are about 2 million deceases linked to mine-related illnesses, translating to over 2 million deaths every year and a death each 15 seconds (International Labour Organisation, 2020).

In 2019, South Africa's Mineral council reported that the mining industry registered the lowest rate of fatality in history. Since the year 1993, there was a decrease in mining deaths by about 92% in 2019 alone while the injuries dropped by about 72% in the same time period (Pelders & Nelson, 2019). The fatalities in 2019 were at 51%, a 36 % decrease year-on-year. Thirty percent of all injuries in South Africa's mining sector rise from proximity to machines and/or hit by the mining machines. Despite the fact that mineral council has put in effort to guarantee that individuals are treated properly and have completed treatment, ninety percent (90%) of individuals working in the mining industry have also tested for tuberculosis (TB) (Ehrlich, Franzblau & Meyer, 2018). The Minerals Council reports further that since 2008, the TB and silicosis incidences are decreasing by sixty-three (63%) and fifty-six percent (56%) respectively. The 2019 statistics above show sharp declines in the years 2017 to 2018, with the silicosis incidents decreasing by twenty-nine (29%) during such time, as well as TB incidents decreasing by twenty-four percent (24%). HIV counselling had also increased to 83% in recent years (Cloete, 2020).

The 1995 Safety and Health in Mines Convention No. 176 sets out the occupational safety and health standards for the industry of mining. The convention regulates the health and safety issues exclusive to working in mines, including the special work devices, inspection, and the personal protective equipment (PPE). The convention also recommends the requirements connected to rescue of the mines (Botha, 2017). Mozambique, Botswana, South Africa, Zimbabwe and Zambia are the Signatories to this convention in the Southern African Development Community (SADC) area (Moroe, Khoza-Shangase, Madahana, & Nyandoro, 2019). South Africa's mining industry has committed to the zero-harm principle with the intention that each mine employee must return to their home uninjured daily (Elgstrand, Sherson, Jørs, Nogueira, Thomsen, Fingerhut & Coulson, 2017). Section 24 of South Africa's 1996 Constitution states that everybody has a right to an environment that is not injurious to their well-being' and health. South Africa's 1996 Mine Health and Safety Act No. 29 and Mine Health and Safety Act regulations regulate the safety and Health in mines. Apart from setting the limits for the dusts in mines and such other pollutants, the above law and its regulations prohibit work in environments containing dangerous concentrations of noxious fumes, dust and such damaging gases short of efficient PPEs (protective apparatus) (Pilusa, & Mogotlane, 2018).

2.4.2 Workplace Safety

The 1996 Mine Health and Safety Act No. 29 (MHSA) includes the Mine Health and Safety Act as well as the Mine Health and Safety Regulations (SAFLII, 2020). Fundamental to South Africa's Mine Health and Safety Act is the tripartite strategy to mine safety and health, that is, the government, workers' unions and industry working together to promote workplace safety and health (Minerals Council South Africa, 2020). There are three (3) principles that arise from this MHSA, placing duty on the mining industry stakeholders for safety and health on mines: for the employer, the responsibility and duty is to safeguard the safety and health of personnel exposed to the occupational safety and health risk and hazards. For the state, the responsibility and duty are to efficiently regulate safety and health conditions at the mines and workplaces. For the employees and miners, the duty is to decline work where the environment might threaten their safety and health. The regulations of the MHSA offer detailed provisions on mine safety and health, explosives, electricity, explosions and fire, safety and health committees, equipment and machinery, Mine Health and Safety inspectorate (MHSI), trackless portable machineries, mine ecological engineering as well as occupational sanitation (The Mine Health and Safety Council, 2020).

2.4.3 Health and Safety Code

The leading health and safety concern in South Africa is that all South Africa's mine regulatory instruments, including the codes of practice and regulations are outcomes-based statements where in contrast in performance-based approaches like Britain, outcomes-based approaches are nuanced (Kleyn & Du Plessis, 2016). Whereas the Health and Safety Executive (HSE) usually follows the goal-setting method, prescriptions are more suitable for mining situations. The other international tendency is the failure to consolidate all the occupational health and safety (OHS) legislations in South African into a single all-embracing statute, as well as the merger of all OHS responsible institutions. (Macfarlane, 2019).

One leading observation form accident research and studies is that South Africa's mining companies have not efficiently engaged employees in approaches that permit them to communicate to the management their explicit OHS worries, contribute own tacit and experiential work and OHS hazard knowledge (Mpufane & Kohler, 2019). The poor or adversarial labour relations defeat any partnerships and communications between the workers and managers on safety and health. Phakathi's (2017). Study on Production, Teamwork and Safety in Deep-Level Mining identified as significant managers willingness to listen to their personnel as well as appreciation of the employees of ways the safety deliberations shape the decisions of management. The other barrier to efficient engagement is the concerns of company management that any participatory procedures undermine their operations control. Research indicates that current audits of internal responsibility systems establish that companies in which supervisors and workers are heavily involved in work planning are mines with few accidents (Ehrlich, Franzblau & Meyer, 2018). Employees have a central interest in safety and health because it is the workers' lives, limbs and health at risk.

With reference to VISION ZERO, the seven (7) golden regulations on safety and health in mining consist of; leadership, hazards, targets, technology, competence, people and safe, healthy systems (Mohapi & Zarske, 2018). In regards to leadership, all employers, managers and executives are in charge of health and safety at the workplace and mines because the leadership quality determines the practice of health and safety standards as well as attractiveness, success and sustainability of the mining enterprise (Baloyi, 2018). From the above, decent leadership requires open-mode communication as well as a clear administration culture that is characterised by attentiveness, predictability and consistency.

2.4.4 Risk Identification and Assessment

In terms of hazards, risk assessments help the mining companies in the identification of risks and hazards before occurrence of production interruptions and accidents. Risk assessments also assist in the evaluation of risk potentials, establishment and documentation of the essential safeguard measures (Coulson, Stewart & Saeed, 2019). Safety and health improvements occur with correct identification and resolution of hazards and/or the factors contributing to industrial risk. The leading risk management components are necessary: risk assessment, hazard identification, controls implementation, controls monitoring, controls adjustment redesign and/or review. Risk management practices at the mines helps the employees appreciate and understand that: a) efficient risk management remains centred around good designs of engineering and work systems; b) the designing of risk elimination and control strategies decreases risk likelihood or consequence; c) risks reduction is by having low hazardous material inventories at workplace or mining sites; and d) repeated accidents only occur if there is forgetting or no appreciation of preceding accidents (Panhwar, Mahar, Abro, Ijaz, Solangi, & Muqeet, 2017).

In regard to targets, successful occupational safety and health requires clear objectives and real implementation steps, established through workplace programmes. Mining companies must establish and prioritise clear OSH goals aimed at consistently reducing accidents, focused on set themes like machine operations, PPEs, or dust exposure reduction. Successful occupational safety and health also requires regular communication of goal achievement to employees (Mohapi & Zarske, 2018). In terms of technology, safe mining facilities, production workplaces and machines are important for free-accident conditions of work. Effective industrial health and safety strategies comprise technical, personal and organisational measures (Mardonova & Choi, 2018). The technical measures take superiority and include maintaining OSH standards for facilities, machines, workplaces and equipment to minimise or exclude detrimental health effects. Competence requires Investment in employee skilling and training. Systematic deployment of trained and well-qualified persons is essential for injury-free workplaces (Kiziroglou, Boyle, Yeatman, & Cilliers, 2016).

2.4.5 Employee Engagement

In terms of people, employee motivation to work in a healthy and safe manner requires mining enterprises to demonstrate appreciation of the employees as well as active involvement of the employees in health and safety conversation to tap into their potential, that is, their ideas, knowledge and abilities (Amponsah-Tawiah & Mensah, 2016). Employee consultations while conducting risk assessments or the development of the operating directions improves their readiness to obey such rules, shapes their attitudes and motivates them to safely undertake their work with confidence and awareness. The objective for everybody is to look after themselves and colleagues because, for the healthy and safe systems, the systematic organisation of OSH assists the mining enterprise to run smoothly. There are less production downtime, disruptions and reduced quality problems. Where check-lists and the implementation of an OSH system of management allow ongoing perfection (Palo & Rothmann, 2016).

In the recent years, the systems notion has helped South African mining companies to develop answers to issues of safety and health in mining (Wang, Zacharewicz, Traoré, & Chen, 2017). In order for the companies to achieve occupational safety and health, there must be involvement of the system mechanisms, the stakeholders, the occupational safety and health committees and procedures, policies, detailed accountabilities, standards, monitoring and auditing, performance indicators and protocols. The system dynamics arise from the interactions and actions of the above components, including leadership, commitment, involvement, consultations, planning, regulator interactions, positive response to difficulties and audit-result actions. Sharp components of the company are an advantage yet in its absence of the involvement, there is unlikely commitment, responsiveness or feedback, performance of the system (Broks, 2016).

Systems-thinking evidence prevails in South Africa’s OHS laws, workplace policies and programmes as well as approaches to engagement of stakeholders, risk assessments as well as accident investigation. The South African Government must emphasize greater collaboration in safety and health efforts through continuous and constructive discussions with employees and businesses (Maluleke & Pretorius, 2016). The regional inspectors have to continuously work with trade unions and employers to resolve problems and establish safety operations like working with international consultants on mining (Stewart & Nite, 2017). The inspectors review mine designs as well as back the right parameters and best practice directives for departments on mine management (Webber-Youngman, Grobler, Gazi, Stroh & Van der Vyver, 2019).

2.5 AUTOMATION AND ROBOTICS IN DEEP MINING

2.5.1 Definition and Nature of Robotics in Deep Mining

Automation of mining equipment falls within four main forms, that is, remote control, teleoperation, driver assist, and full automation (Murray, 2018). Remote control mining equipment refers to the mining vehicles like bulldozers or excavators that operators or miners control using hand-held control. The operator uses remote control and stands in line-of-sight to undertake the usual functions of the vehicle (Peng, Du, Cheng & Li, 2019). Due to the heavy reduction in machine feel and visibility, there is general reduction in productivity of vehicle using the remote control. Remote control technologies enable the mining apparatus to function in unsafe conditions like unstable terrains, blast regions, underground mining and/or high threat falling debris areas (Li & Zhan, 2018). Remote control technologies are a less costly approach to mining equipment automation, making them a perfect point of entry for businesses intending to try robotic technology viability in mines.

Teleoperated mining equipment means vehicles an operator controls at remote locations with the use of sensors, cameras, and perhaps additional software for positioning (Tanimoto, Fukano, Shinohara, Kurashiki, Kondo & Yoshinada, 2016). Teleoperation permits the operator to remove further themselves from a mining site and have control of the vehicle from a safer environment. Through teleoperation software, operators use Joysticks and/or other hand-held devices to control the functions of the vehicle and have better access to the positioning data and telemetry of the vehicle (Valenzuela-Urrutia, Muñoz-Riffo, & Ruiz-del-Solar, 2019). While the removal of the operator from the mine cab allows teleoperated vehicles to experience decreased productivity, the operator nevertheless has an improved point of vantage than the remote control of on-vehicle sensors and cameras. The operator is also safe of potentially hazardous conditions (Dempsey, Kocher, Nasarwanji, Pollard & Whitson, 2018).

According to Ralston, Hargrave and Dunn (2017), full automation means the independent control of a mining vehicle(s). The components of the robotic manage every critical vehicle function like steering, ignition, acceleration, transmission, braking as well as implement controls like dump bed and blade controls as well as excavator boom and bucket without operator interventions. Fully autonomous systems of mining experience the leading productivity profits because the software controls mining vehicles to permit the operator to assume the role of troubleshooting faults, mine facilitator as well as monitor efficiency (Jacob, Yamin, Perez-Storey, Hopgood & Lapkin, 2017).

Driver assist means partially automated controls of the mining machinery (Kiziroglou, Boyle, Yeatman & Cilliers, 2016). The leading functions comprise both the collision avoidance and spotting assist systems. While driver assist is a feature that is more in automaker vehicles, the mining sector has come to appreciate that individuals are logically cautious of surrendering their robotics control over to the artificial intelligence (AI). The driver-assist technologies, therefore, make people contented with some autonomy. Mining machines with the driver assist structures can similarly park and remain in lanes as they cruise on the freeways (Ziebinski, Cupek, Grzechca, & Chruszczyk, 2017). For the mining vehicles, features of Driver assist are the first low risk and affordable phase in changing from the manual to fully self-directed mining fleet.

Robotics means the intersection of technology, science and engineering which produces apparatuses, termed robots, which replicate or substitute human activities (Chakravorty, 2019). Robotics also denotes the interdisciplinary area of research at the computer engineering and science interface which comprises construction, design, use, and operation of the robots. Robotics is intended to plan intelligent machineries that will assist and help humans in daily lives as well as keep everybody safe (Kumar, Mishra, Kumar & Prasad, 2018). Existing equipment in mining is hydraulically and naturally motivated, and electrically or diesel powered. Often, the workplace tools and/or the end-effectors are situated at a distance from the power source and operator. There are high masses and loads as well as expensive equipment (Marshall, Bonchis, Nebot & Scheding, 2016). Robotics advancement and large-scale application of such devices have augmented the want for robots' computer simulations.

Mining researchers are correspondingly designing fresh robots, undertaking task development of prevailing robots, performance evaluation and cycle-time estimations (Macfarlane, 2018). In regard to robotics application within the industry of mining, both opencast and underground mining need such technologies (Jacobs & Webber-Youngman, 2017). Robots perform an extensive assortment of mining-linked tasks like laying the explosives, going underground when the mining has stopped to alleviate the roof as well as mining in areas where it is impossible for people to survive or work. Additionally, to some of the above-mentioned responsibilities the robots perform at the mine, the devices are predominantly valuable in their capacity to meaningfully reduce the accidents at the mining site. Sutherland (2020) states that the leading robotic technology applications in the industry of mining currently are: a) robotic devices for bolting and drilling mine roofs; b) underground mapping or navigation devices; c) machine automation like automatic load-haul-dump trucks; d) devices for position evaluation; and e) the mine issues evaluation technologies.

In terms of robotics, mining equipment is mobile, heavy and compliant. Localization, mostly total localization, is extremely difficult (Ruiz-del-Solar, Vallejos, Asenjo, Correa, Parra-Tsunekawa & Mascaro, 2016). The environment of operations may similarly be dangerous, in regard to higher temperatures, acidic and salty water as well as exposure to robust and rock fall treatment. The equipment might be dangerous to individuals, in the period of transition before complete robotic mines, the human safety issue is dominant. Current sample mining robotics are fundamentally converted machines, yet over time, they change to be purpose-constructed robotics (Knutsen, Kotsadam, Olsen & Wig, 2017). Mining robots can vary from robots that assist in excavation, to robotic devices with camera systems that detect gases and other materials. Most outstandingly, companies can use mining robotics for keeping safe the humans (Jacobs & Webber-Youngman, 2017). In regard to the robotics scope, numerous robotics approaches require detailed information of the cutting tool position. The underground mine environment remains predominantly challenging for correct localization (Dehghan Firoozabadi, Azurdia-Meza, Soto, Seguel, Krommenacker, Iturralde & Zabala-Blanco, 2019). To resolve the issue in the longwall situation, South

Africa has developed the shearer position measurement system (SPMS) founded on the inertial navigations to measure correctly the shearer's three-dimensional position.

2.5.2 Types of Robotics in Deep Mining

2.5.2.1 Autonomous and Sensing Navigation

Autonomous and sensing navigation includes sensor-directed autonomous navigations as well as systems of sensor-centred vehicle navigation (Dindarloo, 2016). Autotramming of the MDA enable shared control advanced the robotics, in Load Haul and Dump (LHD) vehicles that transport the minerals underground. The operators on the earth surface teleoperates this vehicle throughout the loading and the vehicle runs autonomously all through negotiations before dumping into mineral passes (Gustafson, Paraszczak, Tuleau & Schunnesson, 2017). The systems of guidance do not need installation of any infrastructures in the mines and employ on-board sensors and LIDARs for vehicle localization and paths the vehicles learned during the phase of training.

Figure 2.5: Load Haul and Dump (LHD) vehicles

Source: (Gao, Ma, & Jin, 2019).

Inertial navigation system (INS) technologies are a rational method of measuring machine positioning in the environment of mining (Wu, Fang, Zhang, Liang & Quan, 2020). Advanced and strong fibre optic or ring laser-sensors require no connections or little outside sensors, therefore, are located in the machine covering in threatened locations. For constant miner direction application, autonomous and sensing navigation comprises Honeywell modular azimuth positioning system (MAPS) as well as the Honeywell ore recovery and tunnelling aid (HORTA)

The initial full-survey high wall mining guidance arrangement is today a serious prerequisite for the high wall mining (Wang, Wang, Zhang, Ge & Intelligent, 2018). The sensor of inertial navigation system (INS) is correspondingly applicable to the longwall mining (Liu, Li & Zhang, 2019). Where the companies measured continuously the shearer's actual orientation and position, the companies can use the shearer's supports in the static geometrical relations for calculation of the actual positioning of the supports as well as the whole longwall (Tao, Yang, Li, Zhang, Fu, Jia, & Wu, 2017). Where added to prevailing capability of the manufacturers, the development facilitates consistent longwall-face computerization.

2.5.2.2 3D Monitoring and Modelling

The 3D photo-realistic machineries or models created with devices like the instant Scene Modeler (iSM) as well as the AQUA Sensor offer remote environments to workstations of the operators, allowing virtual presences (Strobl, Mair, Bodenmüller, Kielhöfer, Wüsthoff & Suppa, 2018). Companies use instant Scene Modeler arrangement in the underground mining for assessing 3D mining distribution and monitoring advancement of the mine. Instant Scene Modeler generate 3D representations from arrangements of the stereo camera descriptions. The technician that operates the underground system annotates the models to show mineral concentrations, takes samples, recording their concentration and location within such models (Zheng, Deng, Fan, Du & Zou, 2019). In registering the models in the mine's coordinate arrangement, the technician enters information into the mine's management arrangement and combine it with the rest of mine data to estimate mineral distributions in the 3D, monitor and plan mining the operations.

Mining researchers have developed comparable 3D systems of modelling and deployed the AQUA robotics. For the deep-sea mining, the AQUA sensor documents stereo image sequences and repeatedly evaluates the relative motions and generates the 3D models of a seabed, submerged vessels and coral reefs. The miners equip systems with the inertial sensors to estimate motions in the marine environment (Horner, Naranjo & Weil, 2016). The continuous research emphasises monitoring development of the coral reefs through 3D change detections and evaluating 2D descriptions.

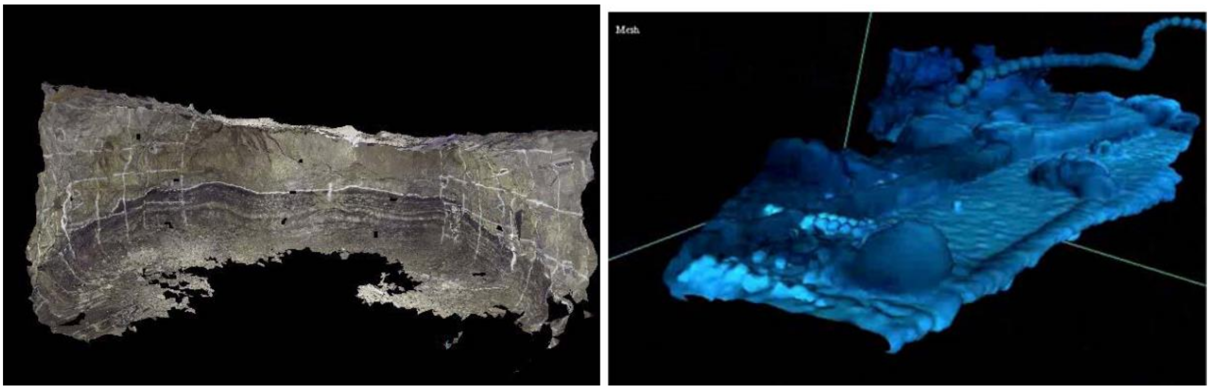


Figure 2.6: The 3D models using the iSM on the left and AQUA sensor underwater on the right.

Source: (Strobl, Mair, Bodenmüller, Kielhöfer, Wüsthoff & Suppa, 2018).

Laser-centred ranging arrangements adapt the surface-grounded laser arrangements to the deep-mine domains. In adjusting to laser-centred technologies, companies must address the deep-mine issues connected to the laser beam backscatter due to deferred particulate material and laser-energy absorption by the mineral column (Gustafson, Paraszczak, Tuleau & Schunnesson, 2017). The companies can reduce absorption effects through suitable laser-wavelength choices. Upon addressing the deep environment details, traditional space- and terrestrial-centred laser technology find application in the marine domain. An alternative to laser-based technologies is the use of multiple cameras (in stereo configuration) sensing technologies to obtain 3D surface structure representations which can later be used for localization tasks.

For purposes of navigation, vehicle localization and obstacle detection, mining companies use devices like AQUA Sensor and iSM for obtaining 3D depictions of the mining environment. Current developments in the 3D image sonars offer reliable and comparable 3D modelling and sensing capabilities underwater, although presently at low determinations than the camera-centred systems (Jiménez-Brenes, López-Granados, De Castro, Torres-Sánchez, Serrano & Peña, 2017). Near real time access to 3D models will significantly increase situational awareness of operators of the remote craft or underwater mining machines by effectively immersing them in the environment. 3D modelling and sensing provide companies with the virtual assessments, best angles of viewing and the precision operation distances. Scanning an environment several times to register 3D models and allow change detections (Palladino, Nasta, Capolupo & Romano, 2018). The aim is to permit mining operations monitoring and environment impact assessment, through direct comparison of the locations.

2.5.2.3 Sensor-Directed Precision Processes

Correct and actual data access in real-time allows autonomous performance of cultured robotic operations (Kiziroglou, Boyle, Yeatman & Cilliers, 2016). Performing unintended precision responsibilities, on cables not intended for robotic repairing, requires a human operator, their insight skills, dexterity and task understanding. 3D vision arrangements that sense the mine situation award the operators some virtual presences through display of the mine models in immersive (synthetic) settings. Such mine environments comprise photorealistic representations from the images and/or range information, models of the known constructions and the kinematic robotics tools and models. The mine operator employs models for planning and rehearsing the operations in a virtual environment before the sequence of the operation is conveyed to the mine's remote position for independent execution (Li, Zhang, Huang, Zhu & Ma, 2017). Companies use on-board processing arrangement and sensors to sense a real setting that provides feedback on force, movement, position to remote tools and robotics and ensure safe and correct operation.

Common control of the deep mine crafts and the mining equipment alleviate teleoperation limitations by independent accomplishment of the mundane operations, retaining task involvement of operators in demanding skills as well as reducing fatigue (Ruiz-del-Solar, Vallejos, Asenjo, Correa, Parra-Tsunekawa & Mascaro, 2016). Reducing the load per craft by operators will permit them to regulate numerous systems decreasing the costs. The need for navigation around the deep mine structures to diminish environmental effect and maximize mineral values, motivate the want for accurate mining competences. Assigning certain control purposes to the independent controller allows the operators to focus on the tasks which require high-level competences. For instance, detailed automatic controls of ROV in regard to the mooring guarantees automatic ROV hovers with regard to the mooring. The pilot focuses on the tasks of manipulation (Vedachalam, Ramesh, Jyothi, Doss Prakash & Ramadass, 2019). The operator can autonomously perform tasks like maintaining the obstacle avoidance and safe distance.

2.6 IMPACT OF ROBOTICS IN DEEP MINING

In deep mining, robotic arrangements operate in contemporary sites of mineral production where they are mostly used as self-directed carriage vehicles. In a majority of instances, the companies prepare in advance the operation areas for robotics application (Leingartner, Maurer, Ferrein & Steinbauer, 2016). The preparations repeatedly include separating the area of operation for independent vehicles from the regions where individuals are given access. The future in mining is underground mining may use robotics in varied situations, with sharing of tasks between machine and miner. Benefits from mobile robotics application in deep mining remain diverse. Government and companies expect improvements in OHS for equipment and people. Additionally, robotics is appropriate for mapping, monitoring and exploration the mining operations (Hermanus, 2017). Robots explore better the dangerous, collapsing mines since the loss of machine achieves no moral and ethical dimension if compared to human life loss.

Robotics which continuously monitor the environmental situations like the air dimensions can contribute to refining the safety and health of personnel in deep mining (Trollip, 2017). Additionally, companies can assign robotics regularly occurrence or dreary workplace routines, yielding the cost and manpower reductions. Correspondingly, companies can increase operation times as well as monitoring cycles using the robotics. The comprehensive, automated, cost-effective and accurate sensor-based mapping of the mines using robotics creates a possibility for qualitative leaps in diverse areas. Deep mining robotics offer extraction planning, exploration, operations optimisation, environmental monitoring and labour protection. Alongside with development in sciences, remote and automated systems shall inevitably result in faster, standardised and simpler operation (Kgarume, van Schoor & Nontso, 2019). While importantly generating the productivity and safety gains, the outcome moves the mining sector closer to better management and reducing huge inconsistencies that today characterize the mining industry.

2.7 CHALLENGES TO HEALTH AND SAFETY, AS WELL AS APPLICATION OF ROBOTICS IN DEEP MINING

The leading challenges in deep mining consist of unavailability of satellite-grounded positioning arrangements or GPS, the roughness of deep mine rough situation and terrain (Ranjith, Zhao, Ju, De Silva, Rathnaweera & Bandara, 2017). The other challenges comprise: a) the operators have low situation awareness because of limited camera interpretations, unnatural light conditions, the absence of the needed 3D perceptions and the non-visual sensory perceptions; b) poor visibility especially if close to the active areas of mining; c) the want for actual and extensive bandwidth of the communication connections to the earth surface telemetry and transmitting images; and d) teleoperation task complexity need more performance like Remotely Operated Vehicle (ROV) navigation which is liberal undertaken; mining tool operations during deep mining. There are extensive tethers indirectly or directly linking to the surface (Uys & Webber-Youngman, 2019). The other challenges are: a) the lack of detailed, accurate and existing maps of the deep mine at the site; b) there is want for maintenance of positioning-scheme infrastructure that enable correct localization; c) the want for deep mine infrastructure supporting of the mine craft and operations; d) the high costs of recovering craft because of failures, operator errors or lack of maintenance. The conditions in deep mines are predominantly hard, that adopting famous robotic algorithms and concepts is always impossible. In addition, the required adaptability and flexibility to execute robotic technologies currently requires expensive solutions that are overshadowed by implementation of focused, skilled, and dedicated conventional miner teams (Komane, & Mathonsi, 2019).

According to Schutte, Kennon and Bam (2016), the leading challenges in deep mining are categorized in four; a) geotechnical risk, that is, the stresses of the rock and ways it affects the tunnel stability and safety. Miners produce very little earth tremors, which are hardly heard on the earth surface. The rock bursts damage the tunnels; b) energy and consumption of energy, that is, as mining employees go deeper, the mines become hotter; c) miners need ventilation to keep them calm and operate in realistic conditions yet the ventilation costs are getting higher in the mining industry. Ventilation costs are the leading costs in deep mining; and d) productivity, that is, way of changing the cost of mining or costs of mining operations (Singh, 2017). There is a need for improved demand for stability and safety in the mining tunnels.

Ranjith et al. (2017) state that the existing advances, prospective, and challenges concerns in deep mining include: (1) Deep mining is becoming common with the gradual exhaustion of minerals at shallow pits. There is restriction of progress and influence of the machine technology and rock mechanic advancement. Therefore, new techniques and theories are essential for South Africa's deep mining considering the elevated mining-induced and *in situ* stresses as well as other conditions of the boundary found at greater depths; (2) there are limited developed and applied control measures for the deep mining disasters like the close rock deformations, rock bursts and inrushes of water and gas mixtures (Kotzé, 2019). Nevertheless, there is little progress in critical technique development in deep mining like control and monitoring techniques for mining-made rock deformations, security and collaborative mining; (3) there is less collaboration of the fast modern technologies development to resolve the restricting development of deep mining either autonomously or through combination of smart mining, improved continuous deep mining as well as fluidized deep resource mining. The approach represents the leading deep mining approaches for the future of the mining sector. Deep mining needs to transition towards fully automation, mechanization, and intelligence; and (4) South African companies have failed to develop new mining technologies for the identification and exploitation of previously unachievable resources and resolution of the growing international demand (Nguyen & Pham, 2019). Deep mining which targets specifically deep and massive mineral deposits requires fresh methods for recovery of materials.

(Fairhurst, 2017) states that the leading challenge to South Africa's deep mining is the enlarged demand for mineral resources, five (5) times faster the growth of population. There is a craving to advance the life quality, particularly in its country-side mining regions. The delivery of acceptable international supply of the minerals remains an indispensable element to the challenge. South Africa's mining industry needs major innovations, including better prominence on research and development (R&D) (Gumede, 2018). From the satellite technologies, examination of new mine deposits is beneficial though there are equivalent imperatives for ensuring development of known deposits and in a consistent manner with environment safety, protection, and economics.

The other challenge to health and safety, as well as application of robotics in deep mines is the hostile working conditions (Macmillan, 2017). Working conditions are increasingly becoming hostile with the increases in depth. Companies have to cool the entire deep system to generate conditions for employee and robotics application underground, there is a need for the mining companies to give individuals applying the robotics suits which keep them and the technologies cool so that they do not push ventilation to keep a low ambient temperature and loss machines to heating and dysfunctionality. While deep mines essentially have ambient temperatures higher than usually acceptable levels, companies have failed to offer better conditions for deployment of robotics as well as suits and special helmet for employees to keep them cool and confidently protect them against fumes or gases from diesel engines. For instance, the companies introduced distinct acclimatization programs in the 1960s at South Africa's Witwatersrand gold mines when the mine was about 2 kilometres deep to prepare the miners for deep mining (Bonsu, Van Dyk, Franzidis, Petersen, & Isafiade, 2017). The conditions result in closure of the mines if combined with decreasing mineral value.

Rock bursts are the other challenge to health and safety, as well as application of robotics in deep mines, mainly South Africa (Morissette, Hadjigeorgiou, Punkkinen, Chinnasane & Sampson-Forsythe, 2017). The Leon Commission stated in 1994 that over 69000 miners lost lives while a million were injured in South Africa's mines. In addition, the commission noted that rock bursts and rock falls are the main cause of the fatalities and injuries in mines (Stewart & Malatji, 2018). While there has been significant improvements and advancement in the development and use of the robotics like remotely-controlled equipment to reduce worker exposures and increase their safety against humidity or heat and such other working stope dangers, there is still need for mine safety controls to evade injury and loss of life and equipment as well as avoid underground operation interruptions (Fairhurst, 2017). The suppliers of robotic equipment have also not carried out adequate R&D on ground or mine controls.

The other challenge to health and safety, as well as application of robotics in deep mines is the recurring threats and risks. Kamunda, Mathuthu and Madhuku (2016) suggest that as employers, companies must address mining risks in deep mining, mainly: a) increased geographical risks arising from sparse information density; b) enlarged capital risks arising out of higher costs of starting mine operations; and c) the intensifying technical risks arising out of increased excavation of the environment for needed materials services, ventilation, handling, ground and employees controls. The current challenges include the advancement of the failure criterion that is appropriate for rocks, guidelines for enhanced block-cave design of the mine based on deeper research and consideration of the caving mechanism, rock burst predictions, and perusals of *in situ* rock masses. Companies in mining must develop ways of seeing inside such block caves to determine issues including unanticipated ground situations (Issah & Umejesi, 2018). The prospect of rock burst prediction remains remote and all we can do is monitor, mitigate, and identify potential high-risk areas. We are also faced with the issue of reducing in situ stress measurement errors to acceptable levels (Zungu, Sibanda & Rajaram, 2018). There is a continued concern for excavation face mortalities in the mining industry.

Limited knowledge and science are the other challenge to health and safety, as well as application of robotics in deep mining. Occurrences in the mining industry like the Grasberg disaster, North Parkes fatalities, Sudbury Basin fatalities, and Beaconsfield mortalities exposed the mining knowledge limitation amongst mining companies. Reports from all the investigations concluded mostly that the conditions leading to the incidents were unforeseeable (Oh, Bahaaddini, Sharifzadeh, & Chen, 2019). The incapability to predict the circumstances is an indication of the employers' existing limitations of risk and deep mine knowledge. Companies need technologies with capacity to penetrate the systems of total covering surface and support like shotcrete as well as thin spray-on liners (TSLs). In due course, the technologies and companies will have the capacity to see what is behind the excavation faces and monitor the block cave interior in real-time. Mining companies need technologies for prediction and mitigation of rock bursts (Morissette, Hadjigeorgiou, Punkkinen, Chinnasane & Sampson-Forsythe, 2017).

The expression that unforeseen ground circumstances is an instance of excuses which mining companies use to stifle the crucial need for required technologies to overwhelm such limitations in knowledge.

Deep mining knowledge need huge investment, especially in deep marine mining like acceptable vessels, the remote tools and monitoring which a few nations can currently manage (Hannington, Petersen & Krätschell, 2017). South Africa does not have adequate geological data or developed deep seabed mapping. There is need for Deep-sea mining (DSM) related technologies as well as huge investments for the processing plants to avoid fatalities and adverse ecological impact Jones, (Kaiser, Sweetman, Smith, Menot, Vink, & Radziejewska, 2017). DSM needs highly dedicated personnel that currently are unavailable in South Africa. There is a challenge of increasing reliable and solid knowledge to back knowledgeable decision-making, particularly in the adoption of ecologically sustainable frameworks for the DSM applications (Childs, 2020). While from the standpoint that minerals are actually non-renewable, DSM remains intrinsically unmaintainable, the argument is that the solid minerals are managed responsibly from the inter-generational viewpoint (Ma, van Rhee & Schott, 2018). However, what remains debatable from the environmental viewpoint is if DSM is sustainably handled insofar as the DSM exploitations surely result in biological, physical and chemical effects. Even though the impacts can entirely be unsolved by technological developments, the Land-centred deep mining continuous to face ecological challenges (Morissette, Hadjigeorgiou, Punkkinen, Chinnasane & Sampson-Forsythe, 2017). Therefore, it is impossible to have expectation of higher environmental protections from Deep-sea mining, which is still facing further issues of inaccessibility as well as gaps in knowledge.

The other challenge to health and safety, as well as application of robotics in deep mining is deprived systems of communication (Jones, 2016). Majority of mining sites lack effective systems of communications, opting to carry cameras and lights (Aleke & Nhamo, 2016). As the separate solution to hard hats, the employers have failed to restructure the worker helmets to integrate all video and light mechanisms on the helmets. Companies have failed to offer personal protective equipment (PPE) and systems of communications for people in deep mines that are stressed, overheated and want to radio throughout the mine as well as on the surface of the mine without hand-held radios (Stone, 2016).

Deprived human resource is the other challenge to health and safety, as well as application of robotics in deep mining. Majority of the individuals working in deep mines in South Africa are in their late fifties (Ngole-Jeme & Fantke, 2017). The males in their late fifties do not focus on their safety and health mostly well, are overweight and with diabetes. With such kinds of safety and wellbeing conditions in very hard, humid and hot conditions of working makes it so vital for companies like Anglo American to have the capacity to monitor health of their people (Anglo American, 2020). The aim is to essentially recognise the high heart rates and such other health issues. Within a decade, South African will require a new generation of employees or miners, a filed very hard to recruit or even attract individuals to work. Correspondingly, there are few women working in the mining industry because they are, particularly not motivated to labour in such working conditions (Kamunda, Mathuthu & Madhuku, 2016). Unless the mining companies provide personal protection equipment, clothing as well as better working conditions, they cannot recruit or even attract youths and women to labour in the mining industry. If the companies want to be sustainable and charm a completely new cohort of individuals, they must keep communicating with individuals because the current generation is not objective.

The other challenge to health and safety, as well as application of robotics in deep mining is the failure to incorporate Best Environmental Practice (BEP) as well as Good Industry Practice (GIP) in deep mining. Conceptualizing the working practices for purposes of handling a business is an essentially challenging responsibility (Guo, Yan, Cai, Ren & Miao, 2020). The challenge is compounded further by the functioning peculiarities of a mining sector like; the *where (*mining in international or national jurisdiction areas), the *when and how (*application of technologies alongside scientific uncertainties on future ecological effect of employed mining methods), the *who (*untried business sector set apart the deep mining from the other industries), and the *what (*minerals which belong to everyone). Such a confluence of legislative and operational features presents an exceptional challenge for mining industry regulation (Kawakami, Konishi, Imai & Soe, 2019).

Firstly, all difficulties associated normally with government acceptance of treaty definitions and terms are augmented in regulatory activities of ISA in deep-sea mining. There is association of mineral exploitation and development with the domestic jurisdictions. The association always comprises a numerous interpretation of the scope and nature of particular terms. As a result, it is difficult for international stakeholders to establish acknowledged BEP and GIP thresholds, terms and definitions (Gerber & Grogan, 2020). Secondly, the mining sector's boundary nature advances itself inherently towards the flux state, causing a shift of supervisory posts. In other words, when DSM undertakings and associated effects on the environment are progressively mitigated and optimized using advanced scientific information and feasible technological progresses which are cautiously practicable, there is an evolvement of thresholds on the constitution of BEP and GIP (Indorf, Cardinale, Gregoire, Conzo, Savy, Alonso, & Hildebrand, 2018).

In turn, the mitigation necessitates an equivalent development of a regulatory setting, when there is recognition and subsequent incorporation of the new prospects into upcoming amendments of the exploitation guidelines (Brown & Burton, 2019). When environmental challenge and unreceptive improvements in deep mining technology only emerge upon the start of the trial mining, the legal prospects formulized before the commencement essentially lack technical and operational detail that influences what is unwritten BEP and GIP terms. Third is that mineral development in areas reserved as part of common mankind heritage concept, place unique obligations and restrictions on chains of mineral commodity value that traditionally are profit-positioned, and subsequently will require a new regulation approach (Mwaura, 2019). Lastly, is that notwithstanding an extraordinary operational location, the main mining activity, herein in mineral exploitation in deep mining, is itself burdened by negative legacies from terrestrial counterparts. Resultantly, mining companies commonly perceive it has possessing a poor track-record of industrial practice as well as negative ecological impacts (Schofield, 2018).

The other challenge to health and safety, as well as application of robotics in deep mining are technical challenges. In Deep mining, the value chain, particularly deep-sea mining offers numerous constraints including mining site remoteness.

Deep mining, specifically deep-sea mining, is only conducted for a few periods of time or days because of energy consumption and autonomy issues (Ranjith et al., 2017). In South Africa, occurrences of minerals at the independent regions offshore are situated at greater depths and so distant of harbours. Companies must bring laboratories to the mining sites because of cost-linked issues. In regard to the nature of technology, actual geological grade measurements of extracted minerals require further advancement. Lifting the extracted minerals into the vessels is significant hard for miners and mining companies (Lodge & Verlaan, 2018). Particular DSM tools and equipment require substantial investment and development in all the many mineral processing and extraction phases.

2.8 THEORETICAL FRAMEWORK

The study adopts the systems theory. Bertalanffy maintains that System Theory is an effort to deriving a universal description of a system. According to the theory, system is the complex togetherness and interaction of components with features of a prearranged whole (Hammond, 2019). Emphasising the system to be a planned whole incorporates Aristotle's "holism" concept which commonly defines the whole as more than a totality of parts. Vanderstraeten (2019) endeavours to make the link that the "holism" concept is a developing representation of structures as a creation of relations working together between machineries to interact collectively with the environment.

For this study and in deep mining, the holistic ways of understanding mining as well as robotics adoption is through shedding more knowledge on organic connections between people, mining environment, national economy as well as the natural resources. Solving environmental and technological problems linked with deep mining is in understanding all original causes, attaining optimal strategies and attractive technical resolutions (Van Assche, Verschraegen, Valentinov & Gruezmacher, 2019). This study maintains that it is only by transdisciplinary involvement, systems thinking as well as robotics adoption in deep mining that mining companies in South Africa can enable collective integration and representation of the different viewpoints as well as improve general understanding of South Africa's mining arrangement.

The way to sustainability of mineral active regions is by sharing of knowledge (Scott, 2019). To understand better the structuring of mineral operations, the industry of mining should therefore generate and employ systems to advance automated mining-level metrics and robotics as well as categorize shared multi-variate procedure patterns. Robotics application and Process mining are a huge, big techniques and tools of data analytics which employ time-series mining information to precisely resolve process features and the growing curiosity in mining.

The study adopted the systems thinking theory as it provides the ability to see how organizational systems such as internal or external conditions, processes and people interact and influence each other. Furthermore, the theory provides the ability on how these systems create and contribute to specific issues such as increased production and health and safety (Senege, 2006).

The theory underpins the study by providing the analysis and synthesis capabilities. With the analysis a logical and step-by-step approach would be used to break down complex mining operations into small processes. With synthesis the theory would provide the ability to recognize the interconnectedness of various components of mining that form the complete value chain of mining. The process involves expanding the thought process in multiple directions and understanding the operation by sensing its patterns. The theory also helps in understanding the gap between understanding and implementation of robotics in mining.

2.9 SUMMARY

This chapter reviews literature on the application of robotics on deep level mining in South Africa, its impact on health and safety. The next chapter discusses the research methodology used for collection of data.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 INTRODUCTION

The chapter presents the research methodology, research design, sampling target (total) population and data collection instruments used for this study. This chapter similarly covers the approach to data analysis.

3.2 RESEARCH PHILOSOPHY

Research philosophy means the belief on the ways of gathering, analysing and using the information of the phenomenon (Dougherty, Slevc & Grand, 2019). Research philosophy means the perceptual alignments and assumptions that researchers share as well as the ways the members interpret both the phenomena of a particular society and the employed research methods to study such phenomena. Research philosophy, therefore, is the arrangements of the theoretical belief that have assumptions on methodology, epistemology, ontology, and methods (Moon et al., 2019). Whereas epistemology concentrates on discovering adequate knowledge, ontology concentrates on the real nature of reality. Methodology denotes the strategy, the process, plan of action or the design of undertaking research. Methods means a particular means of data collection and analysis (Al-Ababneh, 2020).

The leading philosophies of research are constructionism, positivism and interpretivism (Bauer, 2017). The positivism philosophy of research contends that people's beliefs do not adjudicate the absolute guidelines that govern social realities. The positivism research philosophy is of the assumption that true reality conquers people's independence (Antwi & Hamza, 2015). The ontological theory of the positivism research philosophy is that social realism entails people appreciating the earth or universe in its authenticity. Due to reality being contextually free, researchers across different times and regions reach similar conclusions on the researched phenomenon. Objectivism prevails as the epistemological connotation of the positivism philosophy of research because the researcher focuses on the research objectives of a phenomenon (Ryan, 2018). Positivism is therefore of the belief that the existing regulations govern the researched phenomena, with implementation assisting in availing accurate declarations. Positivism believes in the uniformity of the phenomena in the research participants.

Constructionism is a research philosophy or paradigm that regards knowledge not as perception into objective realities, but rather as humanly constructed using societal interactions (Taylor, 2018). Constructionism proponents never endeavour to reveal universal laws which support reality but try to appreciate the immaterial perspectives which people form of specific local places, events and issues (Semenov, 2017). Constructionism never evaluates if there is any truth in interpretations but facilitate sophisticated and informed perspectives. The research philosophy constructionism creates observations from interactions between the participants and researchers (Weenink, & Bridgman, 2017). Social constructionism assumes a serious positioning against knowledge, stresses cultural and historical specificity, accept as true that knowledge production is through everyday interaction and people interpretations are knotted with power kindreds. For constructionism, interpretations are uncoverable through connections amongst participants and researchers and therefore, embraces dialectical debates for resolving disagreements using carefully balanced discussion.

This study employed the interpretivism philosophy of research because it employs sense-formation procedures and/or methods to describe reality instead of hypothesis-taxing actions. Interpretivism research philosophy maintains that the leading social reality is not objective or particular but best appreciated in a socio-significant state of affairs and/or numerous study participants engaging personal discussions (Kivunja & Kuyini, 2017). The justification is that the interpretivism philosophy perceives social reality as difficult to entrench and implement in societal surroundings. While Constructionism maintains that studies create inherent research phenomena connotations, interpretivism maintains that that viewpoint is not strictly detached of social sciences and has to be blended or incorporated therein. Interpretivism focuses on the figures and facts corresponding to the study problem and makes it conceivable for one to appreciate specific situations. In using Interpretivism, this study assessed small samples of data carefully to get hold of the larger population’s attitudes.

3.3 RESEARCH STRATEGY

Research strategy or methodology means the technique a study employed in the selection, processing, identification and analysis of the anticipated information on the research topic (Bell, Bryman & Harley, 2018). The qualitative research strategy, mixed-methods research strategy and the quantitative research strategy are the main strategies or methodologies of research. This study used the quantitative methodology of research so that it can be a collection of scientific proof and generalize across the people describing the specific research phenomenon. The quantitative methodology of research concentrates on the use of mathematical, statistical, numerical data as well as the objective measurement of gathered information (Hong, Gonzalez-Reyes & Pluye, 2018). The quantitative methodology of research, therefore, employs methods like surveys, polls and questionnaires or even handling the pre-existing mathematical data by way of computational strategies. According to Levitt, Bamberg, Creswell, Frost, Josselson and Suárez-Orozco, 2018), the outcomes of the quantitative methodology of research are logically unbiased as well as statistical since data collection is by means of structured measures and run-on larger samples which represent the target (total) population.

The mixed-methods methodology of research blends both the qualitative and quantitative methodologies of research like the points of view, the data analysis, collection and inferences techniques so as to attain added corroboration, depth, understanding and breadth (Bell, Bryman & Harley, 2018). The fundamental characteristics of well-designed mixed-methods research methodologies in research comprise: a) analysing and collecting both open-ended (qualitative) and closed-ended (quantitative) information; b) using demanding procedures in data analysis and collection that are appropriate for each technique's tradition, like guaranteeing the fitting sample size for qualitative and quantitative analysis; c) data integration during collection, discussion, or analysis of data; d) using measures that execute quantitative and qualitative mechanisms either sequentially or concurrently, with the different study samples or same sample; and e) framing the measures within theoretical or philosophical research models like within social constructionism models which seek to appreciate multiple viewpoints on particular issues (McKim, 2017).

The study employed the qualitative methodology of research to understand the study participants' experiences and also expose the actual meaning of the research topic. The qualitative strategy or methodology of research achieves the projected objectivity using visually-focused narratives, textual contexts and also by creating themes that are specifically confined to the research participants (Mohajan, 2018). The qualitative research methodology provides the study with information on the human side of the studied issue, mainly, the contradictory beliefs, behaviours, opinions, relationships, and emotions of the individuals. The qualitative methodology of research is similarly effective for the identification of intangible aspects like social customs, socioeconomic position, religion, and ethnicity, whose part in the studied issue is readily not apparent (Creswell & Creswell, 2018).

3.4 RESEARCH APPROACH

Research approach denotes the procedure with periods of better hypothesis and comprehensive methods of data, collection analysis and interpretation (Woiceshyn & Daellenbach, 2018). The deductive research approach and the inductive research approach are the main approaches to research. Whereas the inductive research approaches concentrate on theory application and creation, pursuit of dominant patterns using observations, explanations and/or hypotheses, the deductive approach of research, on the other hand, focuses on skimming prevailing theories on the studied question as well as directing the research into data collection or ultimately reject and/or confirm the study question (Azungah, 2018). In the inductive research approach, the researcher starts by collecting information that is applicable to their study topic. Once a considerable data amount is gathered, the study then takes a rest from the collection of data to studying the data. At such a stage, a study checks for any data patterns, working to advance a needed theory which can explain such patterns. Therefore, when studies employ the inductive research approach, the study begins with numerous observations before moving from such specific knowledge to an additional but general proposition on such experiences. Studies that employ the inductive research approach move from information to needed theory, from specific views to general experiences.

This study adopted the deductive approach of research because, before the analysis and collection of data, the approach begins with a selected theory to create a study hypothesis from such a theory. The deductive approach of research maintains that although explicit theory disguises certain and prevailing contributory connections, such connection remains accurate in numerous circumstances (Armat, Assarroudi, Rad, Sharifi & Heydari, 2018). Studies that assume the deductive research approach assume the reverse data collection procedures in the inductive research approach. The study begins with a needed theory which if finds compelling before testing the implications of the theory with information. The study moves from the general levels to more particular levels. In the deductive research approach, the study focuses on what other researchers have established, read prevailing theories on the study phenomenon, before testing study hypotheses which arise from such theories. For this study, the deductive research approach concentrated on defining if the prevailing linking between research objectives covers the over-all circumstances.

3.5 RESEARCH DESIGN

Research design entails the predetermining circumstances of analysis and collection of data in a way that joins the significance to the purpose of the study (Walliman, 2017). The study explores the application of robotics in deep level mining in South Africa and the impact on health and safety. The use of exploratory data analysis design is adopted to review the different documents and literature from mining journals and other mining research papers to establish the use of robotics in mining. The study also hopes it would have the potential of gathering challenges related to the application of robotics and their impact to health and safety. The recommendations of the study are expected to enrich the literature. The exploratory data analysis is the most suited in answering the research questions and showing the existing limitations of the literature in relation to the research topic.

Organized collection of data requires cautious assortment of the researched units as well as cautious quantification of each research variable (Creswell and Creswell,2017).

3.6 SAMPLING

3.6.1 Population

(Yin,2017) define target (total) population as the people, units or subjects that fulfil the standards of the research group. The total (target) population means the group of people that the research or intervention anticipates to carry out research on and reach needed deductions from. The South African Mining Industry with deep level operations was the total (target) population for a qualitative assessment of the possible application of robotics on deep level mining in South Africa, its impact on health and safety. The study does not have a population as it analysis existing documents and literature relating to the adoption of robotics in mining in South Africa.

3.6.2 Sampling

According to (Creswell and Poth, 2017), sampling entails choosing individuals from the target (total) population for study purposes as well as generalizing as specified by the outcomes of the sample. Sampling means using a specific subset of the total population for purposes of representing the entire population and/or inform readers of the meaningful processes beyond specific cases. According to (Creswell and Clark, 2017), sample is the representative of the total population for the generalisation of research findings. Non-probability sampling and probability sampling are the main techniques of sampling (Creswell & Creswell, 2018). The probability technique of sampling entails random choosing of the participants who become part of the research sample (Etikan, Alkassim & Abubakar, 2016). Simple random sampling, stratified sampling, multistage sampling, systematic random sampling as well as cluster sampling are the main types of probability sampling.

This study adopted non-probability sampling. Non-probability sampling entails the study using personal decision for the choice of the study participants or sample. The non-probability technique of sampling comprises of calculation of chances for a population participant being chosen as part of the study sample (Tyrer & Heyman, 2016). The most common methods in non-probability sampling are voluntary response sampling, convenience sampling, judgement (purposive) sampling, quota sampling, and snowball sampling. The study adopted the judgement (purposive) sampling technique because it is helpful when the researcher wants to attain comprehensive knowledge on the studied phenomenon than reach statistical interpretations and/or where a population is specific and small. Efficient purposive sampling involves clear credibility and criteria (Tyrer and Heyman, 2016). As the knowledge of the researcher is influential in purposive sampling, there are high likelihoods that the obtained results will be exceedingly accurate and with less error margins.

3.6 DATA COLLECTION

According to (Forrester and Sullivan, 2018), data collection comprising gathering data on the manifestation of the study phenomenon in an organised as well as the recognised manner that permits response of the study sample to research questions and results. The study used document analysis for the data collection on the assessment of the possible application of robotics on deep level mining in South Africa, its impact on health and safety. Document analysis is the type of qualitative study wherein the researcher interprets documents to find meaning in the research (Mackieson, Shlonsky & Connolly, 2019). Document analysis involves repeated examination, interpretation, and review of data to develop empirical knowledge and meaning of the studied construct (Sowden, Borgstrom & Selman, 2021:3). Rubrics are used in document analysis for grading or scoring the studied documents (Wood, Williams, Nagarajan & Sacks, 2021).

The study adopted document analysis due to the COVID-19 situation especially online documents. This study will conduct document analysis on three key kinds of documents: a) Public Records like the ongoing, and official records of the South African Mining Industry, including mission statements, transcripts, annual reports, handbooks, policy manuals and strategic plans; b) individual documents like social media, e-mails, incident reports, blogs, newspapers and peer-reviewed journal articles; and c) Physical Evidence like posters, flyers, agendas, training handbooks, and other materials.

For this study, the document analysis focused on three leading themes, that is, a) the current application of robotics on deep level mining in South Africa; b) the impact of application of robotics on health and safety ; c) identify the challenges to the application of robotics on deep level mining in South Africa; and d) the recommendations to the possible application of robotics on deep level mining in South Africa and its impact on health and safety.

3.7 DATA ANALYSIS

Data analysis means inspecting every collected data for the purposes of attaining specific interpretations, implications and suppositions (Silverman, 2016). The study employed content analysis for data analysis. Content analysis involves quantifying the application of specific concepts, words and phrases (Khairon, Jasmi, Latif, Kanafiah & bin Nordin, 2021). In essence, content analysis involves the study determining all that is searched and organizing the amount and frequency of incidences in the document. The collected data is then prearranged in what is connected to research questions. The study used thematic content analysis as a means to identifying relevant and meaningful passages and patterns. According to (Yu, 2020), thematic content analysis categorizes arises themes for additional analysis and includes focused, careful reading as well as re-reading of information, category and coding construction. The developing themes and codes are also a means to data integration (Vaismoradi & Snelgrove, 2019).

This study also employed the Nvivo computer software for data analysis. NVivo software is the qualitative data analysis software package that assists researchers in analysing, finding and organizing understandings in qualitative research (Dalkin, Forster, Hodgson, Lhussier & Carr, 2021). The study employed tables, pie-chats, figures and graphs for presentation and categorization of identified themes.

3.8 VALIDITY AND RELIABILITY

3.8.1 Validity

Validity denotes the degree to which collected outcomes measure the projected objective (Cypress, 2017). Validity is the extent to which any measuring instrument measures what it is intended to measure. Assessment of validity entails examining the approaches which result and actually agree with in recognized philosophies as well as the procedures of a comparable concept. Validity possesses two important measures in research, that is a) credibility (internal), as well as transferability (external). Internal validity specifies the legitimacy of the study results due to the ways the selection of groups, recording of data or the performance of the analysis. Internal validity focuses on the replication of the study. Therefore, to establish Internal validity, this study used strategies including triangulation, extended contact with the participants, background checks of the participants, reflexivity, as well as peer review of the literature. According to external validity indicates the transferability of whether the research results in a reset of the interest groups.

The test of validity entails four predominant kinds of validity, that is, a) content validity, b) face validity, c) construct validity, as well as d) criterion-linked validity (Creswell & Creswell, 2017). Content validity means the degree to which the research instrument's questions, as well as the question scores, represent every conceivable question which may be raised on the skill or content. Content validity guarantees that the research instrument, document analysis herein, includes acceptable items which tap into the studied concept. The higher the items of scale represent a domain of the measured concept, the superior the content validity. No numerical tests prevail to ascertain if the measure covers sufficiently some area of content. As such, content validity is dependent on the judgment of the field professionals. At the reviewer's advice, there can be an amendment of obscure and unclear questions as well as discarding the non-functioning and ineffective questions.

Face validity means to the extent to which the research instrument or research test seems to measure all it is intended to measure. Where the study never believes the measure is a correct valuation of the capability, the study can detach itself of the task.

Studies use criterion-linked validity for the prediction of current or future performance because it compares outcomes with some other interest criterion (Burns et al., 2017). Criterion-linked validity focuses on relationships between the scores, as well as particular measurable standards. Concurrent validity means the extent to which data collection instrument scores relate with scores from other research or research instruments that already prevails as authentic, intended to measure similar constructs, conducted at similar periods or with certain available valid criterion. For criterion-linked validity, it was necessary when document analysis was constructed to assess personal skills so as to replace fewer effective questions. This study correlated questions with previously validated questions using a pilot study as the standard set. Pilot testing was intended to test the research questions therein and remove biases, as well as resolve and check any looming inconsistencies. To ensure that document analysis properly tested and covered the study objectives, the pilot study for this study included document analysis of six documents. To establish validity and ensure the gathering of secondary as well as primary facts, the study similarly compared the information from the review of the literature so that it could eliminate doubts.

3.8.2 Reliability

Qualitative studies hold reliability to mean trustworthiness. Trustworthiness means the degree to which the research outcomes are reproducible if the event of a recurrence of the study under matching conditions. Reliability also means examining the consistency of the results across diverse observers, time and some parts of the research instrument itself (Cypress, 2017). While in quantitative studies, reliability means result consistency, repeatability and stability; that is, the study's result is held as reliable when there is the registration of consistent outcomes in comparable situations yet different settings, reliability in qualitative research arises when the approach of the researcher is constant across varied projects and researchers. Therefore, the trustworthiness of a data collection instrument arises out of its dependability and consistency with existing literature with similar circumstances and environment of research.

The study used triangulation to establish trustworthiness (reliability). Triangulation, involves use several resources in order to get corroboration and convergence, triangulating is intended to offer a convergence of all evidence which breeds the needed credibility (Creswell & Creswell, 2017). Corroborating the findings of the study across different sets of information reduces the effect of likely prejudice by exploratory information gathered through the different documents and sources. To ensure the trustworthiness, the study endeavoured to focus on the study objectives, and undertook due care in conducting document analysis.

3.9 LIMITATION TO THE STUDY

The study was confined to the South African Mining industry with deep level operations. As such, there may not be a generalization of all the research recommendations as well as research outcomes to the rest of the world or regions of South Africa. Amongst the academic limitations is the fact that certain personnel or members of the mining companies could not participate in this study and/or complete the research instrument as anticipated.

The confidentiality concerns and clause in employee employment contracts or illegal mining caused some of the participants to remain timid to engage in the study or even offer more data on their mining experiences. The COVID-19 situation in the world has made it hard for the study to reach as many participants as possible due to the difficulty in transportation and high costs of internet or online meetings and lockdown restrictions.

3.10 ETHICAL CONSIDERATION

With reference to (Pierce, Steele, Flood and Elliott, 2019) and the ethical considerations raised in the Belmont Report, the study guaranteed that:

a) Attained the needed permissions.

This study attained the needed permissions from the university, participants and mining institutions to conduct research. This study also presented the letter of approval of the university to every study participant before requesting and attaining their voluntary participation and informed consent.

b) No harm on the participants

This study also guaranteed there was no harm on the participants of this study by periodically informing the participants of the research objectives and research aim as well as the right to withdraw at any time if they felt uncomfortable to engage more in the study.

c) Uphold data confidentiality, participant anonymity, and non-accostation.

This study guaranteed the participants of confidentiality anonymity, and non-accostation by keeping all the collected data on a computer under passwords. The study also used fictitious names in the study when referring to the participants. The study will destroy all the gathered information after 2 years as required by the university.

d) Adhere to the objectivity.

To avoid any biases, influence on the research results as well as uphold any other arising ethical concerns, this study adhered to the principle of objectivity. This study used references and citations to recognise and acknowledge all the literature and authors used all through the research process. The study observed all independent investigation and construction of the collected information so that it avoided any external or internal influences on the study participants or even mislead the readers.

3.11 CHAPTER SUMMARY

The chapter details the research methodology, research design, research philosophy, research strategy used to collect information on the assessment of the possible application of robotics on deep level mining in South Africa and its impact on health and safety. The study adopted the qualitative methodology of research and document analysis for data collection. The following chapter covers a presentation and analysis of the collected information.

CHAPTER FOUR: FINDINGS AND DISCUSSION

4.1 INTRODUCTION

The study explored the application of robotics in deep-level mining in South Africa and its influence on health and safety. This study adopted document analysis as its research method to answer three important research objectives, that is: to determine the current application of robotics on deep level mining in South Africa, to identify the challenges to the application of robotics on deep level mining in South Africa and to examine how robotics on deep level mining will impact health and safety. The chapter covers an analysis of the collected data as well as a presentation of the study findings.

4.2 CURRENT APPLICATION OF ROBOTICS ON DEEP LEVEL MINING IN SOUTH AFRICA.

(Macmillan, 2017) studied mining in South Africa in the past thirty 30 years and found that while South Africa seems a leader in equipment and products of mining, the application of new technologies like robotics in deep mining remains excessive enthusiastic. The prevailing technologies used in South Africa's deep mining are generally short of the internationally accepted standards. Deep-mining companies in the nation continue to utilize the traditional approaches to mining. as against the growing challenges like heat, rock bursts, irregular grades, as well as narrow stopes. Unquestionably, the gradual yet cautious application of robotics on deep level mining in South Africa is helping in the resolution of existing hurdles and increases the progress of mining operations in both small and big producers of mineral. Against the rise in deep-mining mining risks and difficulties, heat, rock bursts, the narrow mine stopes as well as unreliable grading. The current technologies in South Africa's deep-mining only allow the 25-metre face advance limit or minimum for every month at the deep levels. There is a need for new and smart technologies to assist the workers and companies in improving excising hurdles. Technologies and robotics will unquestionably increase operational advancement in South Africa's deep-miners as well as key smaller deep-mineral producers.

(Ledwaba, 2017) studied the existing status of South Africa's small-scale and artisanal mining sector and made the following findings. While there is the gradual development and growing application of technical technologies like robotics in deep-level mining in South Africa. South Africa's deep-level mining companies have embraced an increase in robotics and extensive mining methods due to global competition and the need for better access to the mineral reserves. The leading companies in deep-level mining are therefore embracing robotic technologies gradually due to the growing numbers of ultra-deep pits, increases in underground temperature. However, the slow adoption of technologies in deep mining like robotics is posing several challenges to miners and companies, mainly safety, logistics and health.

(Neingo and Tholana, 2016) studied the trends in productivity in the gold mining industry of South Africa to conclude that the mining methods in South Africa remain mostly unchanged for the last ten years. Although pioneering for the region, South Africa's miners still use traditional blast and re-entry approaches to deep mining, cut and fill, drift and fill, stopping and shrinkage, bulk mining as well as pillar and room. Together with such conventional methods of deep mining, depth and low technological application, the productivity of mining labour remains impacted by slow technological advancement. In some of the deep-level mines, it takes a lot of time for miners to reach their deep workplace from the surface. As part of their risk management plans as well as the occupational health and safety strategies, deep-mining companies have indicated the need to embrace technologies in their operations to reduce risk on worker health. However, a few companies are embracing technologies like robotics due to cost implications and the lack of enforcement by government and worker unions. There is, therefore, a need to embrace and integrated the over-dependence on manual workers in deep mines into advanced technologies like robotics and mine layouts.

In their interview, a representative from the platinum mine identified the key challenges to application of robotics in operations as the working conditions underneath. It is much easier to implement robotics to business workflows than to mining operations due to conditions such as underground water, heat, quality of air and fall of rock.

4.3 CHALLENGES TO THE APPLICATION OF ROBOTICS ON DEEP LEVEL MINING IN SOUTH AFRICA

(Fairhurst, 2017) studied some challenges of deep mining in South Africa and other parts of the world and found that the main challenges to the application of robotics on deep level mining in South Africa are the restricted influence and progress of machine technologies like robotics and rock advancement of mechanics, inadequately applied and developed control policies and measures for occurring deep-mining disasters as well as limited cooperation between the development of modern and smart technologies. The current administration has failed to curb restrictive application of deep mining robotics in smart and sustainable mining. For purposes of proper exploitation and identification of formerly unattainable minerals as well as resolution of growing global demand, deep-mining firms in South Africa are failing to draft harmonized policies on technology or robotics application.

(Nguyen and Pham, 2019) studied the development of mining technology tendencies in regards to deep mines and found that deep mining in South African and China faces several environmental and technical challenges, mainly high rock mass stress, higher temperatures and the extended winding distance. There is excessive technogenic catastrophes, stoppage or decreased operations of deep mining and production when compatible methods of mining fail to acclimatize with the conditions of high stress. The failure naturally produces an exceedingly negative impact on viability and performance. The high temperature in deep mines seriously impacts the productivity of the miner and the effectiveness of the cooling, thereby increasing the cost of mining. The extended winding distances, depth and height cause health and safety risks. South Africa's traditional approaches to deep mining are barely able to offer extraction and development safety and efficiency. There is a need for the implementation and development of modern and smart mining technologies.

In studying the socio-economic effects of mechanising and/or modernising hard rock mines in South Africa, (Gumede, 2018) identified cutter wearing, steering and jamming difficulties in complex grounds that have water inrushes, faulted and fractured zones, higher in-situ gas, and stress as the main challenges to the application of robotics on deep level mining in South Africa. Weak ground conditions are the most leading challenge to the application of robotics on deep level mining in South Africa, causing over one-third of all downtimes. In deep mining, increases in depth generally result in vertical stress whereas horizontal stresses increase with tectonic intensity and depth. Excavation unloading causes robotic tunnelling to break all states of stress equilibrium and redistribution of stress. In the incompetent hard rock, stress redistribution likely results in rock bursting, notching, spalling and slabbing at the excavation face and tunnel walls. The abrupt energy releases greatly impact tunnel-support installations and structural integrity, conveyors, cutterhead, damage cutter, grip and muck difficulties as well as high tunnel worker risks. The second biggest challenge to the application of robotics on deep level mining in South Africa after the squeezing and weak grounds is groundwater. Groundwater is borne in hostile geological mines like faults, mine collapse columns, goaf and karst caves. The impact of groundwater is great losses in schedule and cost to fix all machinery and clean up all the resulting mess.

4.4 HOW ROBOTICS ON DEEP LEVEL MINING WILL IMPACT HEALTH AND SAFETY

(Hermanus, 2017) studied mining redesigned-innovation and technology needs for the future a South African perspective to conclude that there is steady application of robotics in contemporary sites of deep-mining, especially self-directed vehicles and carriage. Mining companies often use robotics for access, preparation, separation of operation areas from independent driving vehicles. The leading possible benefits from mobile robotics application in deep mining remain diverse. To impact occupational safety and health (OSH) in deep-mining, South African companies and the government are using robotics to improve exploration, mapping, monitoring of mining operations as well as worker equipment. Robotics explore the collapsing and dangerous deep mines to detect unsafe regions because losing machines have no ethical and moral attachment when compared to people deaths.

(Kgarume, van Schoor and Nontso, 2019) studied the use of 3D ground-penetrating radar to mitigate the risk associated with falls of ground in Bushveld Complex platinum mines and concluded robotics help in the continuous monitoring of the deep-mine environment, mainly the air to avoid pollution the people in the mine. To attain manpower and cost reductions, South Africa's deep-mining companies use robotics for consistent monitoring of cycles and/or dreary mine routines and increase the operational time. Robotics allow miners for the calculation of qualitative dives in diverse deep-mine areas. In deep mining, the robotics all safety experts to plan for exploration, extraction, optimisation of operations, worker monitoring as well as protection. Alongside development in sciences, remote and automated systems shall inevitably result in faster, standardised and simpler operation. The generation of safety and productivity data allows deep-mining companies to reduce inconsistencies in worker health which characterise South Africa's mining industry today. The application of robotics in South Africa's deep-mining allows the nation to shift from the nuanced outcomes-based approaches to mining to performance-based strategies just like Britain.

In their study on digital radiological surveillance of silicosis and related tuberculosis in the South African mining industry (Ehrlich, Franzblau and Meyer, 2018) find that deep-mining firms in South Africa are using robotics to engage mineworkers on best approaches for communication, management of the health and safety worries. The application of robotics in deep-mining has, therefore, allowed mine workers to contribute their own hazard views and knowledge. Robotics has resolved the previously confrontational labour relationship between mining firms and workings and built effective communication and partnerships between the managers and workers. Today, mining firms are willing to use robotic technologies to listen to worker deliberations and appreciate their option on the improvement of safety, thereby participating and shaping management decisions. Participatory operations management permits efficient deep-mine operations and control, as well as auditing of the internal obligation arrangements. The aim is to indicate the workers and supervisors responsible for accidents and/or involved in planning the mines.

4.5 CHAPTER SUMMARY

This chapter presents results on the application of robotics in deep-level mining in South Africa and its influence on health and safety. The chapter establishes that regardless of earlier endeavours and applications in their hard rock mining pre-1994, there has been substantial improvement in robotics exploitation, implementation and performances in South Africa's deep-mining. South Africa's deep-mining firms are gradually embracing robotics in conveyance, access, drainage, exploration, water diversion and supply, ventilation in their underground mines as well as hard and soft rock open pits. The little robotics and technology projects in South Africa's deep-mining in the last twenty years has resulted in various advantages like increases in profit, worker safety and scheduling. This chapter has also indicated that robotics application in South Africa's deep-mining faces both technical and operational challenges arising out of difficult grounds. A majority of the challenges in deep-mining presented in this chapter arising out of South Africa's changing and complex geological situations, people practices and the gradual adoption of technologies due to the fear of losing jobs.

CHAPTER FIVE: LIMITATION, RECOMMENDATIONS AND CONCLUSION

5.1 INTRODUCTION

The study explored the application of robotics in deep-level mining in South Africa and its influence on health and safety. This chapter covers the conclusion, limitations to the study, the recommendations to the study as well as practical implications of this study. The last part of the chapter focuses on suggestions on future studies on deep level mining.

5.2 CONCLUSION

5.2.1 Current Application of Robotics on Deep Level Mining in South Africa

There is gradual advancement of technical capacities in South Africa’s deep-level mining. Notwithstanding the progressive application of robotics and advancement of methods of mining in South Africa, the industry’s mining method remain unchanged largely in the last decades. Deep-mining companies still use the blast-&-re-entry methods in deep-level mines. Currently, the five leading methods of deep-mining in South Africa are drift and fill, cut and fill, room and pillar mining, shrinkage, stopping as well as finally bulk methods of mining like block mining. In line with the methods of mining, mining companies still use the usual drill and blast mining method.

Many mining firms in South Africa are investing in robotics due to concerns of health and safety, increased depths, the extensive application of technologies, methods of exploration in mining as well as the need to attain more access to reserves. The new concern for many key mining companies in South Africa is that the current deep mines are now mining at very deep levels that more depth of the mines will not only increase the mine’s life cost competitiveness but also put the life of workers at a very high risk. The firms are therefore getting engaged in the development and application of mining methods as well as technologies, like robotics and increased mechanisation. The mining projects in South Africa are currently at ultra-deep levels with the shafts at over four (4) kilometres in depth, as well as temperatures beyond fifty-five (55) degrees Celsius. The frequent use of rock bursts under such active circumstances makes mining conditions cause challenges not only on waste and logistics but also the health and safety of the workers.

5.2.2 Challenges to the Application of Robotics on Deep Level Mining in South Africa

Amongst the main technical challenges to the application of robotics in deep-level mining in South Africa is the availability, reliability as well as fail-safe operations of the robotics. The other leading challenges are the capability of mining firms to sustain robotics productivity at existing and/or better dep-level mining. Workers are operating in very unstructured and extreme mining environments as well as a harsh weather. There are such difficulties in supporting and developing the needed robotics technologies as well as environmental infrastructure. Among the many difficulties associated with exploring the flooded deep-mines is robotics navigation in the confined mine spaces, as well as tremendously restricted visibility. To inherently integrate robotics applications and systems, there is need for revolution of current methods of robotics application, mining as well as designing of sustainable methodologies. The other challenges to robotics application are field deployment due to differences in South Africa's deep-mines. There is a shortage of proficient and skilled workers as well as re-training of existing workers.

In a majority of cases, people attitudes, including the senior managers as well as firm executives, indicate the fear of job losses to robotics application and automation. Although changes in the generation are alleviating the challenges, there is an overreliance, risks, and robotics proliferation in South Africa's deep-mining industry. South Africa's mining companies have not engaged workers in the application and automation of robotics in the mines nurturing unfavourable behaviour and making the deep mines unsafe and risky. There are challenges to education and equipping of the mine personnel with needed skills to adjust to robotics application in a quickly changing mine environment. The challenge in developing and maintaining an IoT infrastructure within mines is that the mine environment is always changing and expanding. The lack of appropriate research on worker experiences and robotics application within South Africa's mining environment has incrementally affected performance of deep-mining. The application of robotics in South Africa's mines is presently limited because of unfavourable polices and immaturity technology application in tasks of deep-level mining. South Africa's government and mining stakeholders have failed to collaborate and transform robotics supervisory and management systems. The adaptability and flexibility required to apply robotic currently requires high-cost resolutions. The non-dedicated and unfocused robotics application teams outweigh the applications of unskilled employees.

5.2.3 How Robotics on Deep Level Mining will Impact Health and Safety

Robotics will improve exploration, mapping, monitoring of mining operations as well as worker equipment. Besides preventing employee accidents in the deep mines, the application of robotics in deep mines will decrease the costs that mining companies devote to health and safety of the workers. In addition to their constant operations, robotics with automatic hauling and drilling abilities have the capability to take away human operators from the hazardous deep-level environments while instantaneously assisting the mining firms to increase employee productivity. This study concludes that the concept of robotics application is one of an important feature for detection of mine fault lines and pressure zones. Robotics help with employee engagement and avoidance of mine areas with weak walls or faults.

5.3 LIMITATIONS

One of the leading limitations to this study is there are few current publications peer-reviewed articles in south Africa on application of robotics in deep-level mining in South Africa and its influence on health and safety. Majority of the prevailing literature in South Africa is old for the current research. The study had to triangulate global literature and South African literature to reach an informed conclusion. Some of the deep-level mining-connected techniques, methods, and theories remain in the early stages although the outcomes in the studies used herein reveal mechanical features of deep-level mining in South Africa. The reason for such limitations in contemporary theories is that the theories in South Africa's deep-level mining remain founded on material mechanics. The theories are comparatively non-related to the mine's depth and/or activities of field engineering yet the new deep-level mining techniques and theories are essential to application of robotics and consideration of mining-made characteristics.

The Covid-19 pandemic and current situation in South Africa is the other leading limitation to this study. The Standard operation procedures, current situation in the country and world made it hard for the researcher to visit various government institutions, mines and libraries for data collection. The researcher opted for online data collection but had to also incur additional costs in subscribing to online libraries for the needed literature.

5.3 RECOMMENDATIONS

There is need for new deep-level mining techniques and theories, especially those considering the mining-induced and high in-situ stresses as well as other boundary or wall conditions found in the great mining depths. To promote robotics application, the South African government and deep-level mining businesses must have several quality assurances measures like the evaluation, standardization, and inspection of the robotics quality. There is a need for additional robotics testing, evaluation, and certification as well as follow-up on South Africa's standard work-related developments so that deep-level mining and disaster rescue robotics obtain a legal foundation to entering mine fast and advancement of work standardization.

Underground operations and ownership of South Africa's deep-mines, robotics application and rescue operations must remain founded on regulations and policies. South Africa's deep-mining firms must improve their six systems expenditure like mine control systems and monitoring, communication, systems of worker location, emergency aversions, as well as compulsory air self-assist. The companies and government must establish policies and strategies on fault avoidance, emergency rescue expenses and equipment, maintenance and layout of deep-mine facilities, emergency evacuation expenses, configuration of emergency shelter apparatus as well as emergency trainings.

5.3.1 Practical Implications

This research prevails as one of contemporary studies in South Africa on the application of robotics in deep-level mining in South Africa and its influence on health and safety. The research shall contribute to elimination of existing perceptions on worker and operator health as opposed to the value of deep-mining automation and mechanisation in South Africa. This study emphasises further the significance of an all-embracing stakeholder consultation in the application of robotics in deep-level mining in South Africa and its influence on health and safety. The research provides base frameworks for the classification of different understanding of deep-mining automation and mechanisation levels in South Africa's mining industry. The study indicates that the different deep-level mining levels are, in need of different stakeholder interventions in the undertaking of change administration initiatives as well as robotics application in deep-level mining in South Africa.

5.3.2 Future Studies

There is need for further studies on comprehensive approaches to the socioeconomic effect of robotics mechanisation and application in South Africa's deep-level mining industry. There is need for further studies on the ways South Africa's deep mines can gain more from uniform integration and alignment in a manner that reflects the initiatives of the mining industry than focusing on individual mining company initiatives. Further research on these topics will permit easy resource allocation. In the pursuit for mitigation of the socio-economic effect of robotics application and mechanisation in South Africa's deep-level mining, there is a need for studies on how mining companies can progressively incorporate the changes in their programmes on change management, health and robotics application. Robotics application in South African mines is still at primary levels. For effective protection of workers' health and safety, there is a need for more exhaustive and technical research on the features and quality required in robotic technologies.

There is a need for in-depth quantitative and qualitative studies on the impact of robotics application and mechanisation on the health of employees, with particular focus on variegated societies, both worker-sending societies. Future studies need to focus on the relationship between the close proximity of South Africa's communities to location of the deep-mine. There is a need for future studies to focus on the effect of government-stakeholder consultations in creating labour-permanent units. The aim will be indicating which stakeholder is responsible for the coordination of health and safety initiatives in the deep-mining industry and project management services. The need for these studies emanates from the clear absence of health and safety ownership, policy initiatives by the South African government and the stakeholders of the mining industry.

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