THE APPLICATION OF MECHANISED TECHNOLOGY TO SOUTH AFRICA'S BUSHVELD UG2 TABULAR OREBODY.

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A research report submitted to the faculty of Engineering and the Built Environment, University of the Witwatersrand Johannesburg, in partial fulfilment of the degree of Master of Science in Engineering.

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DECLARATION

I declare that this research project is my own unaided work. It is being submitted to the degree of Master of Science in Mining Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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(Signature of Candidate)

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ABSTRACT

Platinum is important to South Africa. For South Africa to remain a relevant global player, mechanisation is the future.

Mechanisation in South Africa's Bushveld narrow, tabular UG2 orebody has not always delivered as per expectations. This has retarded modernisation of the platinum mining industry. Mining companies have considered reverting back to conventional mining methods.

This report investigates, through a series of interviews with key industry players the reasons for the failures.

By comparing practice with the recommendations in seven areas: - orebody characteristics, mine design and layout, mine logistics, mining machine size, machine utilisation, labour force structure and change management issues, gaps holding back mechanisation are identified.

These are;

- Applied technology and Orebody – the ore body and its characteristics are not always compatible with the mining method and technology applied.
- Mine design & layout and Mining – Mining layout is informed by extraction strategy and should support safe, effective and economic mining. This has not always been the case.
- Move and Mining – Movement of ore and people has not always been seamless. This is a logistical issue which if not addressed adequately in the design phase will cripple a mechanised operation.
- Maintain and Mining – Plant and machinery must be available in - shift to support mining activities. Effectiveness of planned maintenance must be applied, measured and quantified. This is not always the case.
- Skills and Mining - Selection, training and placement of personnel is essential in the successful operation of a machanised operation. This is true for the entire hierarchy of the organisation. A trackless operation cannot be successfull if run by people with no appreciation and respect the machines they operate and manage.

- Health & Safety – Mining.There is a reduction in injuries when mechanised operations are compared to conventional operations. Mechanisation however brings its own sets of safety and health issues. Examples are: -
    - Injuries in mechanisation are more severe.
    - There are no current interventions to health disorders caused by machine vibrations and diesel emission.
- Ethics and Mining – It is the responsibility of all to eliminate the wilful damage to plant and machinery.
  Machinery must work at all times that it is planned to be utilised. The culture of reporting for work when scheduled to do so is paramount.

Future reseach should be directed at addressing each of these gaps.

DEDICATION

Mabel and Saul Samapundo

Thank you for the selfless love and parenting.

My late father and mother Philip and Enara Tendaupenyu

Thank you for giving me hope.

Andile, Vuyi, Gqwesa, Ngqiqo and my lovely Qaqamba Mtotywa

Thank you for making me one of yours.

My wife and son, Nawaal and Imraan Rutendo Tendaupenyu

You, are the reason I get up and try again. Thank you for the support.

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To Doctor Gordon Leslie Smith. Thank you for making me see the other side. Who would have thought I could?

To my Supervisor, Doctor Declan Vogt. Thank you for the guidance and encouragement. You made this study possible.

To my colleagues, friends and contacts in the industry. Thank you for your time and facilitating access to areas of study.

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AIDS	Acquired Immune Deficiency Syndrome
AMMSA	Association of Mine Managers of South Africa
AMRE	Association of Resident Engineers
ASD	Advance Strike Drive
BRPM	Bafokeng Rasimone Platinum Mine
CEO	Chief Executive Officer
CONOPS	Continuous Operations
CSF	Critical Success Factors
DMR	Department of Mineral Resources
DMS	Dense Media Separation
ETF	Exchange Traded Funds
FOG	Fall of Ground
JSE	Johannesburg Stock Exchange
HAVS	Hand Arm Vibration Syndrome
HIV	Human Immunodeficiency Virus
LGBTI	Lesbian, Gay, Bisexual, Transgender and Intersex
LHD	Load Haul Dump
LTI	Lost Time Injury
LTIFR	Lost Time Injury Frequency Rate
MSD	Musculoskeletal Disorders
MSZ	Main Sulphide Zone
NASA	National Aeronautics and Space Administration
NIHL	Noise Induced Hearing Loss
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacture
OMP	Occupational Medical Practitioner
PGM	Platinum Group Metals
PPE	Personal Protective Equipment
ROM	Run of Mine
RPT^{21}	Respondent Number 21
RPDS	Rapid Mine Development System

TB	Tuberculosis
UCS	Uniaxial Compressive Strength
UG2	Upper Group 2
ULP	Ultra Low Profile
VHNR	Vickers Hardness Number Rock
XLP	Extra Low Profile

1 INTRODUCTION

Various authors and industry watchers have made observations that have shaped, and continue to shape opinions about the sustainable extraction of Platinum Group Metals (PGMs) bearing UG2 orebody in South Africa's Bushveld Complex.

Cramer (2000) initiated the platinum industry sustainability discussion. He observed that 65% to 75% of the mines' operating cost is attributed to the mining activity. Of this cost, 60% is the fixed cost of labour. Other cost drivers in the Bushveld Complex have been increased depth of mines. He further stated, "the industry must break out of the low level of training, the unskilled job content, and large numbers required underground—if not for survival at the lower end of the cost curve, then at least to reduce the exposure of men to underground conditions" (Cramer 2000:278). Ounces being mined have become expensive. A labour force debilitated by HIV and Aids is increasingly getting sick. He finished by saying that soon the vast numbers of unskilled labour, used in the present archaic mining methods, will not be available.

More recently, Cutifani (2014) contributed to the conversation by stating that employed labour is unproductive and has brought about 30% value destruction in the metals commodities industry listed on the Johannesburg Stock Exchange (JSE). Fisher & Schnittger (2012) stated that economic growth can only be achieved by increasing productivity. This can be achieved by the on-going revolution in technology. This background defines what Porter (2014) described as 'the need'. There has to be a need for the adoption of new technology.

The narrative of the four authors and others is still pertinent. Well before 2000, the industry had made attempts to move away from traditional, conventional mining. It experimented with various types of technology, often at great cost. The results have not reflected the effort. If anything, mine salvage yards along the platinum belt are littered with abandoned carcasses of expensive technologies and various trackless equipment.

Productivity still remains elusive; labour costs are continually increasing, at times at more than the inflation rate. Failure by the industry to sustainably address these fundamentals resulted in disasters such as the Marikana massacre. It is against this background that the research problem is formulated.

1.1 Research Problem

Continued failure of tabular UG2 mechanised operations to meet expectations has retarded the modernisation of the platinum mining industry. This has resulted in mining companies considering reverting back to conventional mining methods.

1.2 Purpose of Study

The purpose of this study is to investigate the possibility of creating mining sustainability in South Africa's Bushveld UG2 narrow tabular orebody by modernising and applying mechanised technology.

1.3 The Objective of Study

The objective of this study is to: -

- Reiterate the need for application of mechanised technology into South Africa's Bushveld UG2 narrow tabular orebody.
- Investigate why mechanised technology as applied to South Africa's Bushveld UG2 narrow tabular orebody has not always been successful.
- Highlight future benefits from the successful implementation of Mechanised Technology in current operations.

1.4 Delimitation of the scope of Study

The study focuses on the primary platinum production from tabular UG2 mineralisation. The mines to be evaluated are those owned and operated by the various mining houses in the Eastern and Western Limbs of South Africa's Bushveld Complex.

Where conventional mining is investigated, it is for comparative purposes.

1.5 Significance of the Study

Forrest, et al. (2010) state that South Africa is the repository of 90% of the world Platinum Group Metals reserves.

This study is significant because failure by South Africa to sustainably exploit these reserves will impact the world's supply of PGMs.

1.6 Outline of the Report

The introduction given in Chapter 1 describes the current scenario, leading to the development of the problem statement. By identifying and stating the problem, the need to develop alternative methods of extracting UG2 in the Bushveld Complex is established. This is the purpose of this investigation.

To further clarify the importance of the study, this chapter highlights the research objectives. The scope of the study is defined so as to narrow and confine the investigation only to the areas of interest.

Chapter 2 provides an overview of the global platinum mining industry. Primary and secondary producers are identified. The role of primary producers, and in particular in South Africa, which has 90% of the global platinum group metals reserves, is discussed. In addition, the role of PGMs in today's world is also argued.

Finally, the environment in which the platinum industry operates is analysed.

Chapter 3 presents the literature review on pertinent themes. These themes include the orebody, mining method, people, health and safety, and extraction methods other than the current drill and blast methodology. The investigation addresses how the above inhibit the application of Mechanised Technology in the Bushveld UG2 mining.

Chapter 4 highlights the research methodology used. It explains the rationale of the research design. The research approach and method used will indicate how the study was conducted. The sampling method, data analysis techniques and research instruments used are also explained in this chapter.

Ethical considerations, as expected for this type of study, are explained before data is collected. The method of checking the validity and reliability of the collected data is stated.

The chapter concludes with an explanation of the limitations of the study.

In Chapter 5, the detailed results of the study are presented in accordance with the research problem and objectives as outlined in Chapter 1.

Chapter 6 discusses the results and findings recorded in Chapter 5. This chapter also draws on empirical evidence discussed in Chapter 3 to conclude the findings of the study.

Chapter 7 draws conclusions from the analysis in Chapters 5 and 6. Based on these, I provide recommendations on the continued failure of tabular UG2 mechanised operations to meet expectations which has retarded the modernisation of the platinum mining industry, resulting in mining companies considering reverting back to conventional mining methods.

As per the significance of this study, the report discusses areas requiring further investigative research. The report concludes by providing references and appendices.

2 OVERVIEW OF THE PLATINUM MINING INDUSTRY

2.1 Global Platinum Production

The Platinum Group Metals are:

- Platinum
- Palladium
- Rhodium
- Ruthenium
- Iridium
- Osmium.

They are rare metals and are found together in nature. They have similar physical and chemical properties (Fernandez, 2017).

Figure 2.1 shows that world platinum group metals production is dominated by:

- South Africa
- Russia
- Zimbabwe
- Canada
- United States
- Colombia
- Other sources.

In terms of global supply, South Africa and Russia produce 89% platinum and 82% palladium respectively. Expectations are that South Africa, Russia, Canada and Zimbabwe will for the next decade continue to be the principal sources of Platinum Group Metals (Wilburn,2012).

Hilliard (2002), posited that in South Africa and Zimbabwe, mines are being exploited for primary platinum production, whilst in Russia and the Americas, secondary platinum is mostly recovered from primary copper and nickel operations.

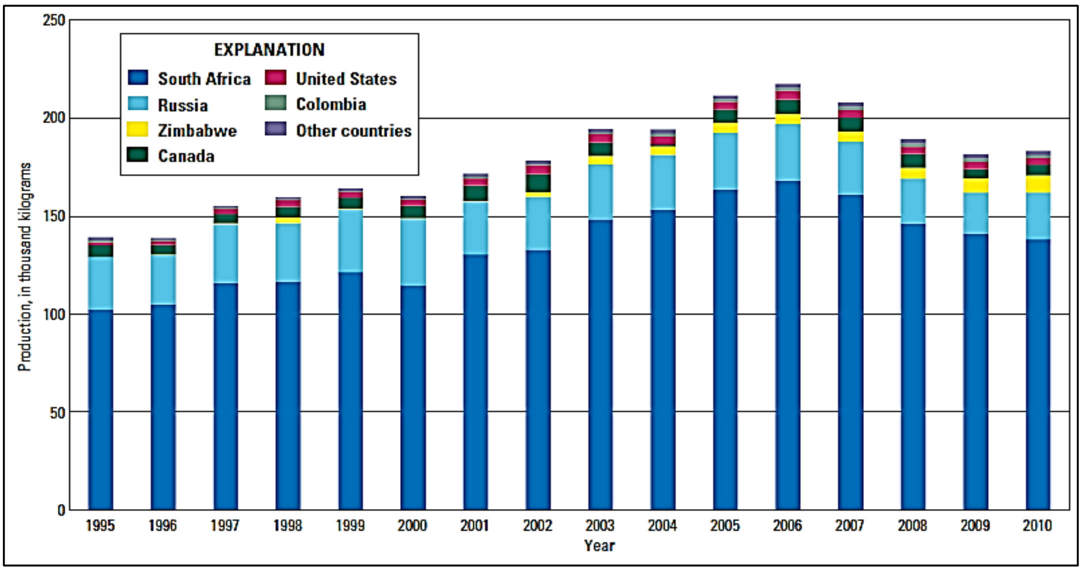


Figure 2.1 Worldwide production from countries producing significant refined platinum from 1995 through 2010. Production is measured in kilograms of platinum recovered. Refined production for the purposes of this chart is from primary sources only. Data are from Reese (1997), Hilliard (1998 – 2011), George (2006 – 2010), and Loferski (2009 – 2011, 2011A,B).
[Source: Wilburn, D.R., 2012, Global exploration and production capacity for platinum-group metals from 1995 through 2015 (Version 1.1): U.S. Geological Survey Scientific Investigations Report 2012–5164, 26 p., at http://pubs.usgs.gov/sir/2012/5164/.]

2.2 Global Platinum Distribution

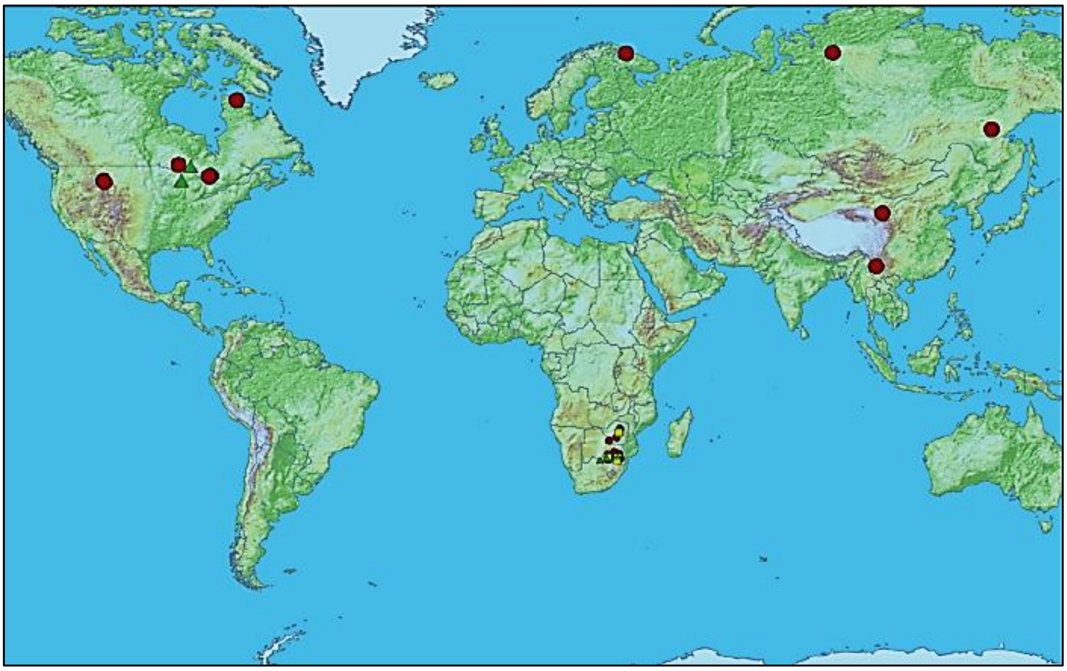


Figure 2.2 Map of the world showing the locations where Platinum Group Metals were produced in 2010 (red circles), where facilities were being developed (yellow squares), and where sites were at such an advanced state of exploration that the deposit was likely to begin production by 2015 (green triangles.) Base derived from Global Multiresoltion Terrain Elevation Data 2010 and data are from Johnson Matthey plc. (2010) and Butler (20100, p. 16 – 23) [Source: Wilburn, D.R., 2012, Global exploration and production capacity for platinum-group metals from 1995 through 2015 (Version 1.1): U.S. Geological Survey Scientific Investigations Report 2012–5164, 26 p., at http://pubs.usgs.gov/sir/2012/5164/.]

In South Africa, the primary measures are contained in the Bushveld Complex. The deposits exist as tabular layered suites (Cawthorn, 1999). More recently, work by Zientek, et al. (2014) on the occurrence and distribution of Platinum Group Metals has validated earlier work by Hilliard and Cawthorn.

2.3 South Africa

The Bushveld Complex has an area of 65 000 square kilometres covering parts of Limpopo, Mpumalanga, Gauteng and the North West Province. The complex contains the world's largest known repository of platinum, palladium, rhodium, ruthenium, iridium and osmium.

The Eastern, Western and Northern Limbs were formed by a series of injections of molten rock, followed by recrystallization of different minerals at different temperatures. This created the layered tabular structure consisting of distinct mineral strata. The limbs all have the same geological age (2 billion years). In the Eastern and Western Limbs, Platinum Group Metals are contained in 25cm wide bands in the Merensky reef, and 50 to 100cm wide band, rich in chromite, in the UG2 reef.

The major producers of platinum and platinum group metals in South Africa exploiting this complex are:

- Anglo American Platinum,
- Impala Platinum,
- Lonmin Platinum,
- Northam Platinum,
- African Rainbow Minerals Platinum
- Sibanye Platinum which acquired the Rustenburg Platinum Operations from Anglo American Platinum and Aquarius Platinum.

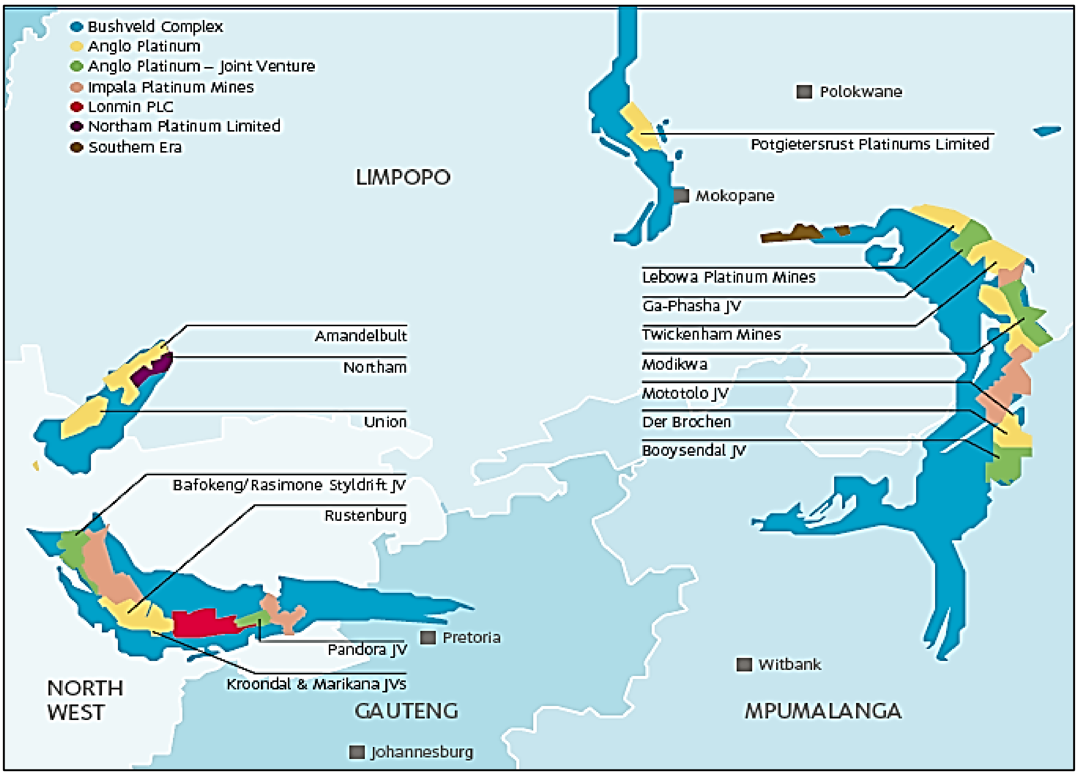


Figure 2.3 Map of PGM producing operations and holding companies in South Africa's Bushveld Complex. [Source:http://www.angloamerican.com/business/platinum/operate/pl_operate01/lv_breakdown.aspx, Accessed 11 June, 2017]

2.4 Platinum Group Metals uses

Uses of platinum group metals are as per pie chart below. These uses are further confirmed in work by Johnson Matthey (2013) and Fernandez (2017) in Zientek & Loferski (2014).

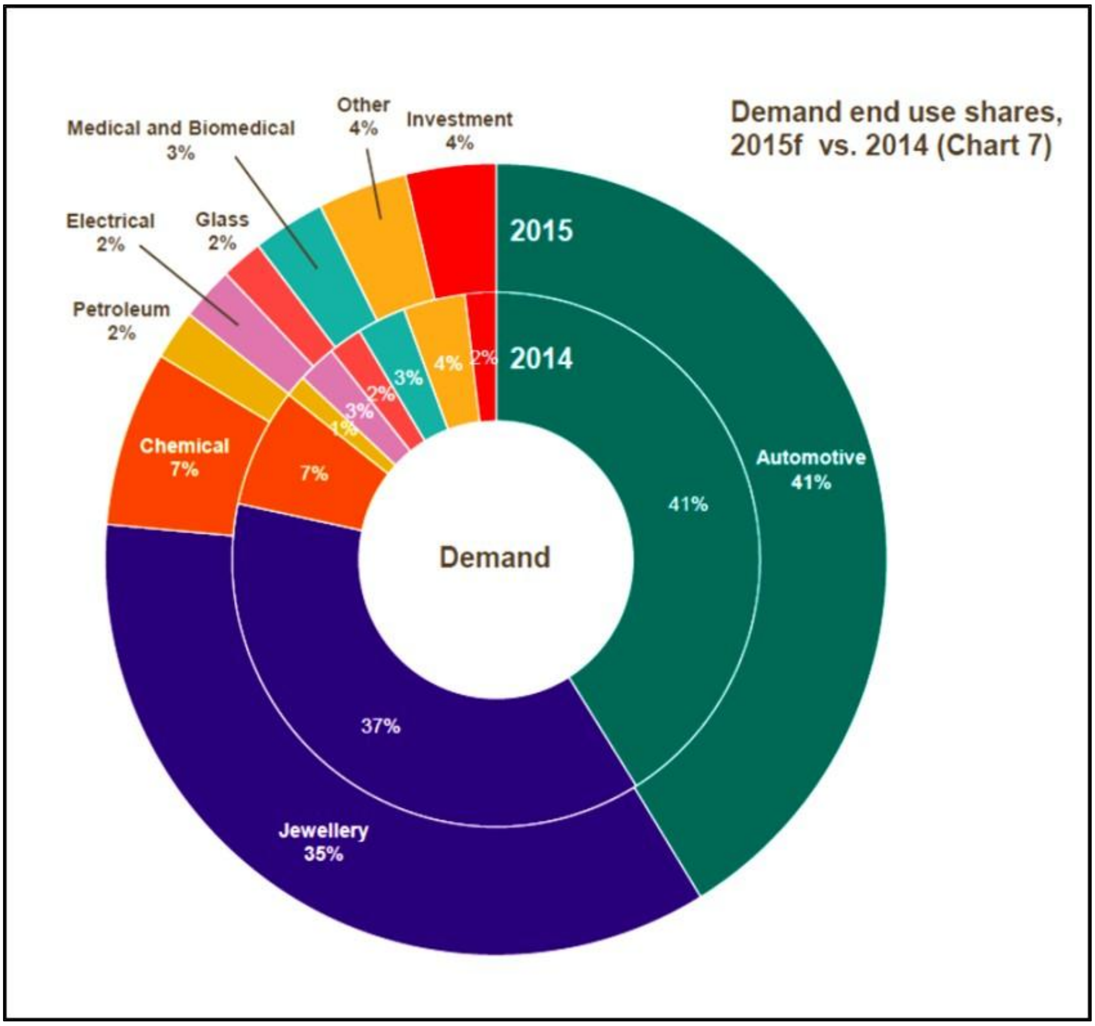


Figure 2.4 Demand end use shares, 2015 versus 2014

Source: SFA (Oxford), 2015 for World Platinum Council

2.5 Macro Environmental Factors of the Platinum industry

According to Yuksel (2012), PESTEL (Political, Economic, Social, Technological, Environmental and Legal) analysis provides a general idea about the macro environmental conditions and situation of an organisation. Below, are the results of a PESTEL study I conducted to assist in the analysis of the macro environment in which the South African platinum industry operates.

2.5.1 Political

There are no external political threats to South Africa. Although the domestic politics have created instability in institutions which sustain the country's constitutional democracy, it is not likely to result in insurrections.

There is a realignment happening among the opposition parties as they collaborate with a view of unseating the ruling party. This state of affairs has brought about policy uncertainty. The lack of trust in government, financial and public utilities has resulted in instability in the financial markets.

2.5.2 Economic Factors

The market for PGMs has been depressed over what Griffith (2017), disputes as the market being oversupplied. While there is this denial, he further states, that loss-making operations have been shut down so as to provide good supply discipline. This will restore profitability of core operations.

2.5.3 Social Factors

Platinum producing areas in South Africa are in impoverished rural areas. Labour employed on the mines has predominantly been migrant, drawn from the labour-sending areas of Eastern Cape, Lesotho, Mozambique and Botswana.

In the Eastern Limb of South Africa's Bushveld Complex, local residents are agitating for employment to be from within their own communities. There is a demand for sustainable development where mining houses have to obtain a Mining Licence after complying with the requirements of the Minerals and Petroleum Resources Development Act (Act No 28 of 2002). Requirements of this legislation are being enforced by the South Africa's Department of Mineral Resources.

2.5.4 Technological Factors

As technology improves, so does the application of platinum group metals. The list of uses for PGM, as stated above, continues to grow and this drives the demand.

2.5.5 Environmental Factors

Environmental factors relate to the influence products have on the surrounding environment and the ecology. This awareness by society drives sentiment. Society's drive to reduce greenhouse emissions caused by the burning of fossil fuels, and for cleaner energy sources, works towards enhancing the demand for platinum group metals.

In addition, the United Nations protocols on pollution and greenhouse emissions are ceasing to be optional. (Report of the World Commission on Environment and Development, 1987). While the appetite for diesel may have dropped, it remains the fossil fuel of choice in heavy plant machinery. (Griffith,2017). This will maintain the demand for catalyic converters.

2.5.6 Legal Factors

In South Africa, the mining industry is regulated by:

- The Minerals and Petroleum Resources Development Act (Act No 28 of 2002)
- The Mine Health and Safety Act of 1996
- The Basic Conditions of Employment Act (Act No 75 of 1997)
- The Labour Relations Act (Act No 66 of 1995)
- The Employment Equity Act (Act No 55 of 1998)
- The Mining Charter (2010).
- Basic Conditions of Employment (Act 75 of 1997)

These legal frameworks complement efforts by multilateral conventions, such as those formulated by the United Nations, to enhance sustainable development and to protect societies (Department of Economic and Social

Affairs of the United Nations, 2015). In South Africa, these laws are policed and enforced. The impact of the recently announced changes to the Mining Charter (2016) is yet to unfold.

2.6 The Platinum Business: Porter's Five Forces Industry Analysis

In assessing and evaluating the competitive strengths and position of the platinum business, Porter's 5 Forces Model has been utilised. The model is based on the concept that there are five forces that determine the competitive intensity and attractiveness of a market. The analysis provides an understanding of the current strength of an organization, as well as where an organization may look to move (Grant, 2011).

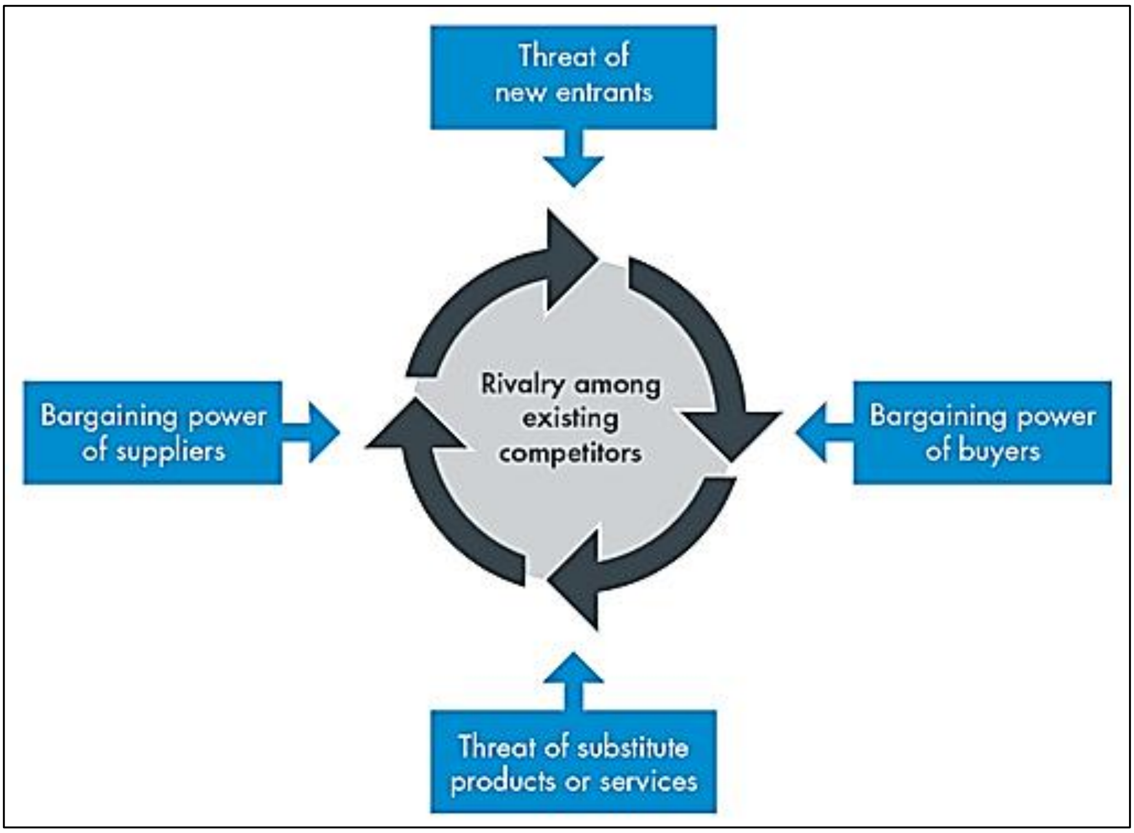


Figure 2.5 Porter's five forces of competitive position analysis.
[Source: **http://www.cgma.org/Resources/Tools/essential-tools/Pages/porters-five-forces.aspx,** Accessed 11 June, 2017]

2.6.1 Threats of new entrants

The status quo is likely to be maintained. Only Russia has had recent discoveries of Platinum Group Metals deposits. However, because of lack of local infrastructure and investment capital, these deposits are unlikely to turn into mines in the foreseeable future. (Johnson Matthey, 2012).

The natural endowment of PGMs South Africa has over the other platinum producers creates a barrier to entry for other entrants. South Africa can influence pricing through supply management.

As happened with gold, an improvement in recovery technology resulted in tailings dumps remining becoming viable. Examples are the Rustenburg's Western Limb Tailings Remining (Roberts, 2006) and the Phoenix Platinum Project (Mining Review, 2010). Phoenix has since been commissioned and is in full production (Pan Africa Resources Plc, 2017).

Recycling has been on the decline from 2015 through to 2017 (Johnson Matthey, 2017).

2.6.2 Buyer Power

The platinum business remains a price taker. The bulk of platinum produced is for:

- Auto catalysts (41%)
- Jewellery (35%)
- Industrial (16%)
- Investment (4%).
- Other (4%)

While current supply is 5% below demand, the price for PGMs has remained depressed. (Johnson Matthey, 2017).

2.6.3 Supplier Power

PGMs are from the traditional suppliers of South Africa, Russia and others. No shocks in supply are anticipated.

South Africa's power supply crisis and the union-led labour unrest of 2014 and 2015, which threatened the supply of PGMs, have stabilised.

2.6.4 Threat of Substitution

Chemically, platinum group metals are interchangeable (Burke, 2009), but the price received for each element differs. Platinum is being substituted as an auto catalyst by palladium and rhodium (Burke, 2009). This same trend has been observed in the jewellery market with silver competing with the palladium market.

This influences the metal prices and, as a result, the platinum group metals business.

2.6.5 Degree of Rivalry

South Africa, by virtue of its platinum group metals endowment, has a competitive advantage over the other producers. As a result, South Africa has the ability to control global supply, which in turn influences pricing. Because South Africa is the major primary producer there is no threat from possible rivals. Except for Zimbabwe, the others are mostly secondary producers (Hilliard 2002).

2.7 Conclusion

This chapter provides an overview of global platinum mining. Primary and secondary producers are identified. The role of the primary producers and, in particular, South Africa, and the role of platinum in today's world is discussed.

Finally, the platinum mining industry, as well as the environment in which the platinum industry operates, is analysed. PGMS are important to South Africa and will remain so in the medium to long term. It is important to ensure that production and productivity are sustained.

3 LITERATURE REVIEW

3.1 Introduction

The first phase of the literature reviewed and presented here was used to determine, and define, the need for modernisation by the application of technology and mechanisation.

In the second phase, the information gathered here was used to design questionnaires. These were used as research instruments to address the problem statement – "Continued failure of tabular UG2 mechanised operations to meet expectations has retarded the modernisation of the platinum mining industry, resulting in mining companies considering reverting back to conventional mining methods."

The need is based on the high costs of labour (Farren, 2002), unproductive labour (Cutifani, 2014), geotechnical challenges caused by increasing mining depths (Cramer, 2000), and extreme underground environmental conditions (Carroll, 2012).

The challenge is cleary defined by Farren (2002:2): "We continually discover technologies, which promise superior results than those currently employed. Yet, when the time comes to deliver, the results achieved seem to fall short of our expectations".

To facilitate investigation into these assertions, further literature was reviewed and additional observations made. Various authors explicitly or implicitly have expressed views influencing the successful application and implementation of Mechanised Technology.

3.2 Orebody

The orebody and its characteristics determine the mining method to be used. It is during the concept and feasibility study phases that all geotechnical parameters, extraction methods, extraction quantums, and other engineering applications are determined.

Smith (2012) identifies the following physical attributes of a mineral deposit as the constructs influencing the mining method, as well as the exploitation technology to be applied:

i. Size of deposit
ii. Mineral content of deposit
iii. Depth of deposit below surface

Smith (2012) says that the selected mining method informs the mining, extraction strategy, scale of operation, designs and layout. He further says this is a depletion plan covering the entire mining lease area and is not constrained by time.

Mines designed and commissioned without due regard for orebody characteristics run the risk of having to convert to another method at a later stage. This conversion is often done at great expense. At times, it becomes cheaper to shut down and walk away. Nong (2010) wrote about such failures at Lonmin and BRPM. In July 2017, Platinum Group Metals Ltd issued a press release where they announced the restructuring of their Maseve Platinum Mine. This restructuring would entail an immediate shut down and stopping of all mechanised mining. Resumption of mining operations at a later date would be with a changed primary mining method. The redesigned method will use a selective mining method (Platinum Group Metals, 2017).

Egerton (2004:439) notes the undesired consequences of a mismatch between the orebody and applied technology. He states, “Machines developed have been for massive ore bodies. Little progress has been made in narrow tabular orebodies. The biggest drawback has been excavation sizes that introduced large volumes of waste into the ore stream”.

This same point is dealt with in Pickering (2007). According to Pickering, the technology applied must be appropriate. This appropriateness is determined by demonstrating at the workplace that the intended functions are met and the mining method selected is adequately productive. A simple measure of “intended function” can be an ability to complete a planned mining cycle within a planned time within the stipulated specifications.

At Union Mine, hybrid mechanised mining was successfully implemented at the Declines Section. At the 3 South Decline Section, the project suffered from excessive dilution because high profile machines were utilised. Excessive hauling distances from production face to surface also affected the viability of the project. (Williams & Swanepoel, 2008). This is an example of a mismatch between applied technology and the orebody. (Appendices 8 and 9).

Another example is Union Mine’s 3 North Piggy Project. While low profile suites were utilised, the degree of faulting rendered the use of these machines ineffective. Re-establishing a face back onto a reef, when the reef has been displaced by faulting, requires a considerable amount of re-development in waste. The 3 North project had to be discontinued because of incessant faulting.

Rhodes (2015) had similar experiences at Joel Mine where 5m x 5m x 5m excavations were mined to extract 50cm of reef channel with a value of 5g/t. Needless to say, Joel Mine never made money from the time of commissioning in 1985 until it was redesigned and converted from a fully-fledged mechanised mine to the traditional “archaic” conventional mine in 1995.

Theron in Cornish (2017:2) says, “The UG2 reef south of the Steelpoort fault on the Eastern Limb Bushveld Complex lends itself to mechanised mining because “it isn’t too narrow” – 180 cm (on average) compared to the typical UG2 package of 80 cm found on the Western Limb.” Theron is a believer in mechanisation. He believes, apart from being inherently safe, it is the key to successfully mining the property’s Merensky Reef. Because it is narrow and has lower grades, higher volumes are required to be cost effective. “Our orebody dictates this method”.

Sandvik (2013:110) defended mechanisation by stating, “There have been some highly published incidents where technology failed to deliver comparable yields to manual operations on certain shafts. Dissidents soon began proclaiming the failure altogether of mechanisation.” Rod Pickering continues in the same article, “To claim that mechanisation cannot work in narrow platinum mines is not true ... merely following a one-fits-all approach is more dangerous. Despite the difficulty of extracting platinum in the narrow confines of platinum mines, we believe human hands do not always have to carry out the ‘dirty work’ in order to be profitable.”

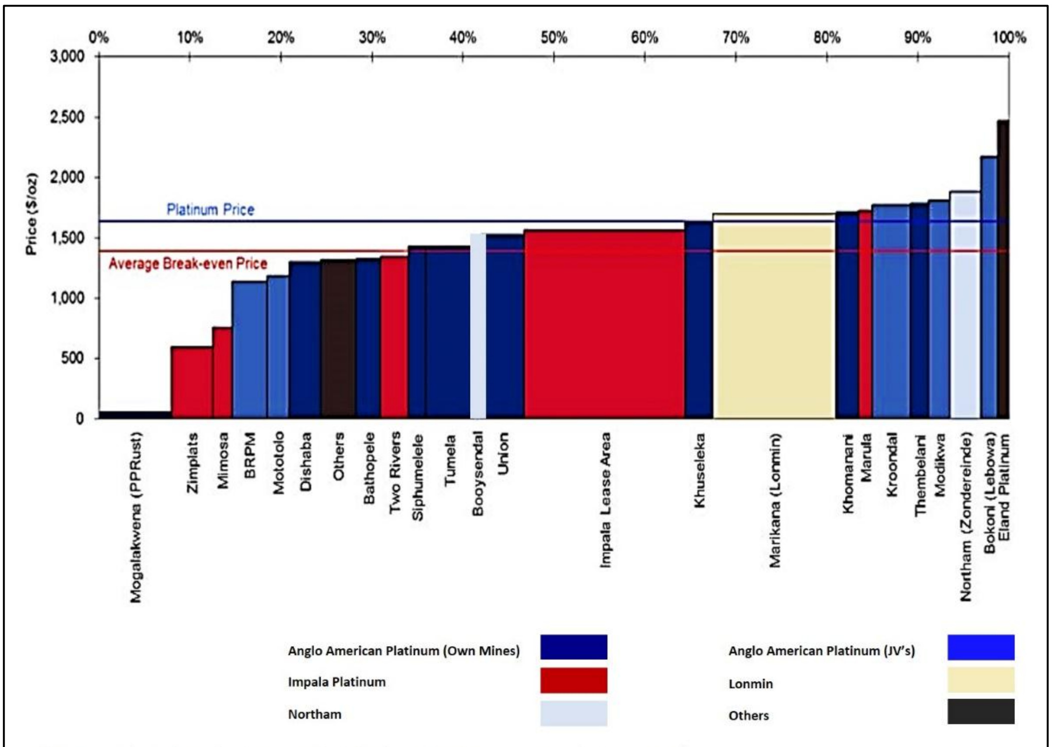
3.3 Mining method

As per Smith (2012), the mining method dictates the mining layout adopted. The mining method determines the foot print. This in turn determines the amount of infrastructure development required before a mine goes into production.

Porter (2014:684) states, “The industry wants to use machines as a silver bullet instead of developing new systems”. Porters’ observation, just like that of Pickering (2007), noted that for the industry to move forward, there is a need to develop appropriate technology, which must be integrated into an improved stoping system. There must be a match. Where such a match does not exist, one must be created. This is achieved through research and development, or through collaboration with Original Equipment Manufacturers (OEMs).

Porter (2014) uses the performance of the platinum sector to illustrate the magnitude of the problem. Figure 3.1 indicates that currently many of the platinum mining operations are not profitable. According to Porter, productivity improvements and restructuring can only address the matter of short-term survival. Long-term sustainability is brought about by changing the way people work. This leads to greater success in re-engineering the mining methods used in the industry. This change is brought about by the recognition of projects that are pushing hard to employ alternative mining methods or the new generation of machines being used to mine the rock.

Note that mines below the average breakeven price are mechanised operations. According to Figure 3.1, all conventional mines are operating at a loss.



Platinum mining industry break-even analysis (cash cost + maintenance capex). *Source: J.P. Morgan*

Figure 3.1 Platinum mining industry break-even analysis (cash cost plus maintenance capex)

At Anglo American Platinum's Bathopele Mine, new mining technology is being applied to a new mining system. While this Ultra Low Profile (ULP) concept, together with its mining layout, has not been rolled out beyond certain sections of Bathopele Mine, the results achieved so far, though limited, are encouraging. This work is documented in Fourie, et al., (2017), (Appendices 10 and 11).

3.4 People

In this report, work by Vogt & Hattingh (2016) is investigated. They stipulate that a requirement for successful technology and mechanisation is a change in people. There is a need to understand why Eastern Limb operators are perceived to be more receptive to change and more effective in mechanised operations than their Western Limb counterparts.

Leonard-Barton (1992) observed that an organisation has core capabilities. These capabilities are distinct technical systems, skills and managerial systems. She also observed that an organisation has core rigidities which inhibit innovation. She termed this dichotomy a paradox. Managers of new products deal with this paradox in one of four ways:

i. Abandonment
ii. Recidivism – return to core capabilities
iii. Re-orientation
iv. Isolation

Without a doubt, the mechanised fleet littering the salvage yards along the platinum belt, more specifically in the Western Limb, has been abandoned. It is important to understand why managers repeatedly opt for abandonment.

Current literature indicates mines which have opted to abandon these machineries have reverted back to the old, tried and tested conventional mining methods. This is a validation of recidivism.

In the hybrid mining method, decline accesses and Advance Strike Drives (ASDs) are developed using trackless mechanised equipment. Stoping operations are conducted using conventional hand-held rock drills and cleaning is done by scrapers. Ore transport from the ASD is provided by Load Haul Dump (LHD) vehicles. The broken ore may be loaded onto dump trucks or strike conveyor belts. This method takes the middle ground. It makes use of a suitable low profile trackless fleet to rapidly develop infrastructure while keeping the core capability of archaic, back breaking, tried and tested conventional stoping. This is a validation of re-orientation.

The Eastern Limb is geographically isolated. Through pressure from the local communities, novice operators are being employed locally. These employees bring with them no baggage from prior faulty learnings.

Cruise (2011) posited that previously, mining was viewed as a ‘man’s game’. Women were expressly barred from being employed underground by the 1911

Mines and Works Act. The view of that time was that women and children should not be exploited in the workplace. Mining was an all-male preserve. Women in mining is an agenda aggressively pursued by the current South Africa government. The industry has embraced it but has never evaluated the impact on productivity. No assessment appears to have been conducted on the impact on women working in what Farren (2002:2) describes as "environmental conditions on the reef horizon are at their hardest. The levels of physical exertion required make it difficult to produce higher volumes with the same or fewer workers". Technology and mechanisation, according to Hatting, et al. (2010) will facilitate the achievement of workplace gender transformation, as well the accommodation of workers suffering from HIV/AIDS. This is achieved by the use of machines to perform the more physically demanding work.

This report will investigate the impact of technology and mechanisation on the productivity of women when compared to conventional, hybrid and other mining method variations as stated in Musingwini & Minnitt (2008).

Other people issues often discussed as impacting on mechanisation and technology are the low literacy rates in South Africa, poor skills levels and the unemployment rate. The possible causes of this are argued in Cawood (2011). Cawood suggests that the education discussion is a result of the mining industry's need to have skilled labour, as well as staff with the potential to be skilled and productive, in order to alleviate unemployment and poverty.

3.4.1 Human factors

People are the key to a successful technology transfer. As Willis and Ashworth (2002) point out, people and not papers transfer technology. So, logically, people in the transfer process must be kept informed. They must be consulted about their needs, concerns, perceptions, attitudes and expectations. They must be trained and mentored to fully understand and utilize the technology to its fullest extent.

The technology may fail because of employee attitudes or resistance to change. This is also referred to as the 'not invented here syndrome'. To prevent this, it is best to avoid imposing new technology on people without ensuring their receptivity.

3.4.2 Training

According to Webber, et al. (2010), supervisor’s performances are impacted if they lack mechanised skills. Lonmin’s Hossy Shaft partnered with the OEM to develop training modules for supervisors that focused on supervision points in a mechanised environment. Training and assessment was done on the job.

Because of the high costs of damages on mechanised machines, training was rolled out to operators. Previously, operator training had been theoretical. Now, however, the new training incorporated the use of simulators. This enhanced skills levels and resulted in reduced machine damages and increased operator skills levels.

Practical skills training was extended to artisans and maintenance supervisors so as to bridge the maintenance gap.

The labour required was reduced but mechanisation can always be utilised to create new wealth and business growth in opening up new sections of the mine. Opportunities for reskilling exist as further training is given to employees. Reskilling provides personal growth as employees become knowledge workers rather than performing their previous menial jobs.

Theron in Cornish (2017:2-3) further states, “Mechanised mining enables you to reduce labour. With a skills shortage in the area, this approach in the longer term poses no threat to employment opportunities for the communities inhabiting the surrounding area. The people we do employ will be better skilled and as such will be rewarded in terms of their wage allocations. The result is a mining operation of the future which eliminates many of the historic challenges conventional mines suffer from.”

3.5 Health and Safety

As the mines are getting deeper and hotter, Cramer (2000) observes that seismicity has increased. In his opinion, the industry must move away from the low level of training, the unskilled job content, as well as the large number of people required underground. If not done for survival and to be on the lower end of the cost curve, it must be done to at least reduce the exposure of men to severe underground geotechnical conditions. Pickering in Sandvik (2013) said the same thing.

Laflamme, et al. (2002) outline three objectives of a Mine Mechanisation and Automation Program.

- Enhancing health and safety in underground mining operations.
- Facilitating mechanization and automation to improve mine profitability.
- Providing sound science to regulatory agencies.

These main objectives are met through two main thrusts; an ongoing effort to develop and improve underground mine equipment and systems, including worker protection and safety devices, and through the introduction of alternative mining methods and systems. A longer-term thrust is related to mine automation and an alternative to explosives to break hard rock.

Egerton (2004) stated among other advantages of mechanisation, health and safety are improved because fewer people are exposed to hazards. Machinery, equipment and systems are intrinsically safer and conditions are generally better.

In June 2007, Lazarus Zim, President of the Chamber of Mines, when referring to the mining industries commitment to health and safety performance, said, according to Pickering (Pickering, 2007:557), “The fact that we lacked improvement in 2006 is a considerable blow to us all. It rather invigorated us to a different course of action. To kick-start a substantial improvement in safety, a new initiative to change the mining process is required. The more traditional approaches to increase safety are having a reduced impact and ‘more of the same’ is not going to do the trick”.

Harrison (2008) claimed improved safety by removing the operator from the sharp end of the production face as a justification for the introduction of trackless mechanised mining in Anglo Platinum.

Webber, et al. (2010:278) shared their Lonmin experiences, “Health and safety within the mechanised operations has performed relatively well when compared to the conventional areas. No fatalities have been recorded in the last four years on the mechanised shafts. The Lost Time Injury Frequency Rates have outperformed conventional areas. Hossy XLP site has achieved, year to date, a Lost Time Injury Free Rate of 2.31. No Lost Time Injuries have been recorded in the stoping or development environment for the year to date. Maximum noise exposure levels have been reduced to below 100 dB in mechanised areas with no new Noise Induced Hearing Loss cases being recorded since 2008”.

According to Lloyd & Cackette (2011), the diesel engine is the most efficient prime mover commonly available today. But diesel is one of the largest contributors to environmental pollution problems worldwide. Diesel emissions contribute to the development of cancer, cardiovascular and respiratory health effects, air, water and soil pollution, reductions in visibility, and global climate change.

While trackless machines are used underground, the diesel emissions do not only affect operators and the environment underground. The emissions are exhausted to the surface via the mine ventilation systems.

Any activity that calls for great physical exertion is defined by Elgstrand, et al. (2017) as ‘heavy work’. Underground mining conditions are such that the work is physically demanding and dangerous. This is because of weighty and awkward loads, unstable underground structures, heavy tools and equipment, and an increased risk of accidents. While this is true for conventional mines, mechanisation - with computerisation and automation - have changed working conditions in modernised mechanised operations. Much of the heavy manual work has disappeared.

While the benefits of mechanisation can be seen, measured and quantified, mechanisation has increased the risks for musculoskeletal disorders. Factors causing this increase are of both physical and psychosocial origin. When the musculoskeletal system is subjected to repetitive and forceful work, static or awkward postures, mechanical stress and vibration, frequent excessive loads, or to loads for long periods, these disorders are created. In extreme positions, i.e. bending, the joints are more likely to be injured. Awkward positions may place a considerable load on certain parts of the body.

Punnett & Wegman (2004) acknowledge there is a debate about the work-relatedness of musculoskeletal disorders (MSDs). They also acknowledge there is confusion about epidemiological principles and gaps in the scientific literature. Despite the confusion, the available evidence is substantial. The rapid work pace, repetitive motion, forceful exertions, non-neutral body postures, and vibration are physical ergonomic features of work frequently cited as risk factors for MSDs.

More data is required to better evaluate gaps in the knowledge concerning the latency of effect. Acquiring this information will benefit everyone.

Elgstrand, et al. (2017) define Noise-Induced Hearing Loss (NIHL) as a permanent affliction that interferes with mine workers' ability to communicate with family, friends, and co-workers. While at work, those afflicted are unable hear moving machinery and warnings. They also experience tinnitus, a ringing or buzzing sound that persists in the absence of any real sound. This is stressful and annoying. The risk of developing Noise Induced Hearing Loss increases with long-term exposure.

The prevalence of NIHL among miners is greatly underestimated because of the delay in the manifestation of symptoms. Miners are often still dependent on hearing protection devices for the prevention of NIHL.

Many countries are also focusing on noise controls for mobile equipment in underground mines, with an emphasis on haul trucks. In addition to noise, several chemicals used in mining have been identified as toxic to the auditory system. They increase the negative effects of noise. Fuels, metals and chemical solvents are examples of such chemicals.

According to Elgstrand, et al. (2017) Vibration Exposure occurs when miners use vibrating hand tools or mining vehicles. Miners working with hand tools experience vibration primarily in their hands and arms, and mining vehicle operators experience vibration over their whole body.

Hand-held jackhammers on conventional operations, as well as trucks and LHDs on mechanised operations, are the source of vibration exposure. Prolonged and extensive exposure to hand-arm vibration has detrimental health effects, primarily in the peripheral blood circulation and in the nervous and musculoskeletal systems. ‘White fingers,’ pain, numbness, or tingling in the hands or fingers are examples of hand-arm vibration syndrome (HAVS). Long-term occupational exposure to whole-body vibration is associated with an increased prevalence of self-reported musculoskeletal pain, especially in the lower back, neck and shoulder regions.

Other occupational diseases include heat and cold stress.

Drilling with hand-held jackhammers, scraping operations and blowing-over during face preparation creates dust ingested by employees. This has resulted in mine employees contracting silicosis (Cowie, 1994). These conditions are more prevalent in conventional mining where all these activities are conducted manually.

3.6 Logistics

Logistics is an all-encompassing term for a variety of activities, equipment and infrastructure supporting primary production.

Webber, et al. (2010.) discussed ore handling. They advocated for the use of vibrating feeders at tipping points. In addition, tip designs should be such that loading delays created by grizzly cleaning are eliminated.

Refuelling and lubrication of machines impacts on the overall availability and utilisation of machines. Webber et al. (2010) note the importance of having refuelling bays underground, as well as an effective diesel distribution system. In their case, it was pumped from surface to a centralized underground distribution point. From the centralized distribution point, the diesel is pumped to the satellite diesel bays located in each section, reducing refuelling times for LHDs significantly and increasing their utilization.

Where mechanisation is used, workshops are a critical component for the success of the operation. These are designed and located for easy accessibility. They must be equipped with cranes, inspection ramps, a wash bay, diesel bay, crimping store, service bay and a refuge chamber.

Callow (2006) itemised some common logistical conditions which affect mechanised equipment performance:

- Workshops - size, location, tooling, lighting, drainage, contamination control.
- Ventilation - cooling, visibility, operator efficiency.
- Haulages - dimensions, clearance, obstructions, footwall, drainage, water, gradients.
- Haul distance - draw point to tip, ramp tramming.
- Maintenance practice - planning mechanical skills, servicing on time, fluid analysis.

Callow further demonstrated that cost per ton doubled because of poor roadway conditions. When roadway conditions are severe, mechanised machines operate in first gear. To improve roadway conditions, operators must be disciplined in clearing roadways of rocks. Good drilling and blasting practices during the roadway development phase ensures good footwall conditions. Above all, good road maintenance in terms of construction, drainage, availability of fines and aggregate for road repairs and lighting are a necessity.

Mabuza (2007) reports access into Two Rivers Platinum Mine underground workings is through a main conveyor decline system developed from surface, as well a chairlift decline for people transport. This has removed the need for people transporters to get employees to their working places. The same transport philosophy has been incorporated in the Booysendal Platinum Mine logistical design.

3.6.1 Shift arrangement

Shift arrangement is a logistical requirement which has a material impact on machine utilisation as the number of shift changes will have an effect.

In Mabuza (2007), the Two Rivers Platinum operation is a full calendar operation, which comprise two 10.5 hour shifts per day. Three production teams are cycled on a 14–7day system. A crew works for 7 days morning shift and then changes over to night shift. A new crew then cycles into day shift and the third crew goes off duty. This effectively gives the crew cycling from day shift to night shift 24 hours break between the day and night shift cycles.

3.6.2 Overall Equipment Effectiveness

Da Silva, et al. (2017,) postulate that mass production companies need to seek high efficiency in the use of equipment and human resources, as well as in the consumption of their inputs. Overall Equipment Effectiveness is a tool for measuring and computing elements impacting on production equipment use. According to Almeanazel & Taisir (2010), OEE is a function of:

- **Availability** as an indicator of the problem caused by downtime losses.
- **Performance** as an indicator of losses caused by speed losses.
- **Quality** as an indicator of scrap and rework losses.

3.6.2.1 Availability

Required availability can be defined as the production time needed to operate the equipment minus the planned down-time like breaks, meetings etc. The down-time can be defined as the actual time for which the equipment is down for repairs or changeovers, sometimes known as breakdown time. This is a critical determinant of how successful a mechanised operation will be.

3.6.2.2 Performance

The performance rate is a function of **design cycle time** to produce an output, the actual **equipment output** and the amount of **operating time**. Loading and hauling equipment output in mining is influenced by, among others:

- Rock fragmentation
- Size of the machine
- Machine abuse - is machine being used for its designed intended use and within its designed parameters, for example gradient/slope
- Tramming turn around distance
- Bucket size and type
- Bucket fill factors
- Condition of roadways
- Efficiency of the machine
- Efficiency of the operator as influenced upon by training
- Environmental factors like visibility, ambient temperature.

The operating time is the amount of time the machine is available and utilised to perform the planned designed work. In a mechanised environment, the number of shift change-overs and line-ups influences the planned shift cycles. Both shifts worked per 24hour cycle, and the distance to refuelling points impact on operating time.

3.6.2.3 Quality

Quality is a measure of the effectiveness of the tasks performed as determined by reworks. The number of passes required to fill up a truck when loading with an LHD is a loading quality measure. Mean Time between Failures and Mean Time to Repair are quality measures on the effectiveness of planned maintenance. These have a direct impact on availability and the production output.

3.7 Beyond Drill and Blast

According to Green & Vogt (2009:1) mining methods in South Africa deep-level gold and platinum mines have remained relatively unchanged for the past century. Recent mechanisation has made some impact in how mining is done, but not what is done. They say “A Robot Miner has the potential to mine in a different way. The Robot Miner is an initiative to address the challenge of safely mining narrow tabular ore-bodies by targeting the ore with an autonomous mining system that is able to mine at significantly reduced stope heights and grades”.

Other reasons for this innovation are the realisation of the inherent inefficiencies of the current drill, blast, and clean cycle operation. One incomplete link in the cycle results in an entire cycle being lost, as all blasting occurs simultaneously in a mine cleared of personnel.

A continuous process will increase the mine efficiency. A novel rock breaking technique is required. The development of such a technique is being pursued parallel to the development of the robotic platform.

Holton & Porter (2012:524-525) observed that sequential processes - drill, charge, evacuate, blast, ventilate, remove rock, loosen, support etc. handicap the advance rate of drill–and-blast mining. The authors believe the gap which exists in the application of Mechanised Technology presents an opportunity for mining to advance.

Furthermore, they say, the effective labour cost component of drill–and-blast is escalating exponentially with time, depth of mining, cooling energy, and safety consequences. They have arrived at the logical conclusion, “that the performance improvement trajectory of mechanical cutter based mining will inevitably cross over the drill–and-blast trajectory. The platinum sector and original equipment manufacturers (OEM) should therefore start to ride the wave of mechanical mining”.

While civil engineering projects have greatly benefited from the mechanical excavation of hard rock, as Gilliani and Butt (2009) state, mining, on the other hand, is still searching for a major breakthrough to modernise, mechanise and subsequently automate the winning of ore (stoping) and the development of access excavations.

According to Petit (2006), UG2 has a UCS of 110 to 120 MPa. Abrasivity, as measured by the Bit Wear Index and determined by the Vickers hardness number rock (VHNR), is 400 to 610. No commercially viable machines have yet been developed with the capability of providing the energy required to overcome these variables. The industry must continue to collaborate with OEMs in pursuing non-explosive cutting disc and pick technology.

Current rock cutting trials have been on going at Anglo Platinum Bathopele and Twickenham mines (Anglo American Platinum New Mine Technology internal document).

Pickering in Sandvik (2013:1-2) stated “as ore bodies are found at greater depths, mining operations will become more difficult and more dangerous, forcing mine operators to adopt smarter approaches ... we are already beginning to push the boundaries of human endurance underground in our platinum mines.”

In connection with current thinking and work being conducted to make mining and processing precise activities, Tony O’Neill is reported in Mining Weekly as saying, “Swarm robotic mining descales mining by making it more precise to execute tasks, mimicking the actions of a swarm of locusts devouring a field or an army of ants working independently”. This technology will facilitate selective mining, remove many people from harm’s way and reduce waste as depicted by ore dilution, and excessive use of natural resources for example energy and water (Creamer, 2017:3-4).

With the modernisation of mines through the introduction of mechanisation and technology, new opportunities present themselves.

South Africa’s failure to successfully deploy machines in the narrow tabular orebody environment of the Bushveld Complex has resulted in automation not taking place. Benefits of mechanisation and automation articulated in the work by Gustaffson (2011) and Lynch & Hamilton (2012) include:

- Safety
- Remote operation
- Operation of more than one machine unit by a single operator
- Improved productivity
- Labour reduction
- Flat organisational structures

Tabular orebody miners of the Bushveld Complex have not benefited from this body of knowledge and the existence of such technology. On the other hand, where modernisation, mechanisation and technology has been embraced in base metals, coal and open cast mining, the benefits have been immense. These include:

- Enhanced productivity
- Enhanced safety
- Reduced operating and maintenance costs

Together, these factors have enhanced sustainability in these commodities.

3.8 Conclusion

Because of the large deposits of PGMs it holds, the South Africa Bushveld Complex is vital to the current and future global supply of platinum group metals. PGMs are not only important precious metals and stores of value, but also most importantly, they have industrial applications.

Current and future global supply of PGMs is dependent on the successful exploitation and sustainable extraction of UG2 in South Africa's Bushveld Complex.

Literature reviewed indicates a decline in productivity in South Africa. Ernst and Young (2014), gave the productivity decline a global perspective. As per the literature reviewed, innovation can stop this downward spiral.

In the same study, Ernst and Young Global Survey (2014:5), Mark Cutifani, CEO of Anglo American said, “Our industry is damned by the fact that our spending on innovation is one tenth of the petroleum industry … if we don’t start to bring innovation back … the major diversifieds will be subsidiaries of General Electric or some other conglomerate that has still got innovation in their vocabulary. Without innovation, they say, returns diminish.”

Fourteen years earlier, Dr Cramer made a similar observation as reported in Cramer (2000:279). Dr Cramer summed up his 2000 Presidential address by saying, “Now, more than ever, as a cursory review of history demonstrates, it is a case of innovate and profit – or die”.

This chapter has also reviewed literature that investigates the “continued closure of tabular UG2 mechanised operations resulting in mining companies considering reverting back to conventional mining methods in South Africa’s Bushveld Complex and so retarding the modernisation of the platinum mining industry”.

The literature reviewed has been used to design research instruments. The instruments have been used to investigate the question, “Despite the support and investment in attempting to modernise the UG2 in South Africa’s Bushveld Complex by mechanisation, why are operations failing to deliver according to expectations?”

4 RESEARCH AND METHODOLOGY

Serfontein, et al. (2009) in Mouton and Marais (2008) postulate that aspects normally included in research designs are research approach, case study utilisation as a research strategy and the research methodology.

4.1 Research Design

Four phases were included in the research design. The first phase was the review of the literature presented here. Secondly, information gathered was used to design questionnaires. Thirdly, interviews were conducted with officials of invited mining houses. Outside of the mining houses, individual opinions of experts in their personal capacities were sought. Finally, this was followed by data analysis, interpretation and reporting.

4.2 Research Approach and Strategy

The research method used here is called Qualitative Case Study. Baxter & Jack (2008) posit that qualitative case study methodology is the ideal tool to study complex phenomena within their context. When applied correctly, this method can be utilised to develop theory, evaluate programmes and develop interventions. Yin (2003), further states, case studies are a preferred strategy when “how” or “why” questions are being asked.

The research question this report seeks to answer is complex, namely how UG2 mineralisation in the Bushveld Complex is exploited and why mechanisation has not delivered to expectation. What has inhibited the successful modernisation of applying mechanisation in UG2 Bushveld mining?

4.3 Research Method

The samples chosen were purposive in terms of invited mining houses, participating mines and interviewees.

The research was conducted on a business unit (mine) in South Africa. A mining house may have several mines in the Bushveld Complex but structural parameters, for example dip and width among others, may be different. The unit analysed had to be operating in the Bushveld Complex and the orebody exploited had to be narrow tabular UG2. This distinction is important. While Mogalakwena mine is in the Bushveld Complex, the reef mined is Platreef and not UG2. Although tabular, the reef is massive and so is amenable to massive mining methods (Cawthorn, 2010).

4.4 Data collection techniques

Below is an explanation of the data collection techniques I employed:

<u>The questionnaire</u> (Appendix 5)
The questionnaire was designed based on the literature I reviewed. It was designed to investigate the reasons why "despite the support and investment in attempting to modernise the UG2 mining in South Africa's Bushveld Complex by mechanisation, operations applying this technology have not always delivered according to expectations."

The questionnaire was used to conduct face-to-face interviews with selected employees on participating platinum producing mines.

Interviews were also audio-recorded and transcribed. Field notes and transcripts of audio-recorded interviews are considered the traditional means of recording data.

<u>Secondary information</u>
Secondary information gleaned from annual reports and other historical records was used to supplement information captured from questionnaires. Observations made were recorded.

Participating mines and employees

The participating mines and their employees that formed the sample selection were chosen based on the following criteria:

- Four mining houses operating in the Bushveld Complex were invited to participate.
- From this selection, two mines from the Western Limb and two mines from the Eastern Limb of the Bushveld Complex were invited.
- On the individual mines, participants were invited randomly based on the functions and roles they fulfilled in terms of the development and execution of mining and extraction tactics and strategies.
- Individual opinions were sought from professionals in their personal capacities. Their opinions are important because of the experience and expertise they possess.

4.5 Data Analysis

The data analysis was conducted utilising the empirical data collected from interviews. The analysis followed the six phases proposed by Braun & Clarke (2006). This analysis was performed using ATLAS.ti.8.

- Phase 1 – The recordings from the interviews were transcribed verbatim.
- Phase 2 – The initial coding was conducted.
- Phase 3 – The codes were consolidated.
- Phase 4 – The consolidated codes provided themes for this phase.
- Phase 5 – The final themes were developed. Associations and contradictions were mapped in this phase.
- Phase 6 is the final analysis and generation of report.

4.6 Issues of reliability and validity

As proposed by Lincoln & Guba (1985), in Morse et al. (2002) conformability, credibility, transferability and dependability provide assurance to the trustworthiness of qualitative research results.

- Conformability – The findings were supported by the data collected from sufficient interviews that reached saturation.

- Credibility and internal validity – The findings of the research indicated respondents' views without alteration. This ensured that findings reflected the true views of all the participants without any adjustment to the original data. To further strengthen the study, data triangulation was conducted. In addition, primary and secondary data was contrasted.
- Transferability and external validity – The research findings can be used by others exploiting a tabular orebody with similar characteristics to understand the challenges in their operating environments.
- Dependability, consistency and reliability – Interview guides were used to eliminate observation error and also ensure questions were asked in the same consistent manner.

4.7 Sampling techniques

Sampling was purposive, targeting personal networks within the industry. As per Diamantopoulus & Schlegelmilch (2000), sample members were chosen with a specific purpose and objective in mind "to investigate why mechanised technology, as applied to South Africa's Bushveld UG2 narrow tabular orebody, has not always delivered according to expectations".

Mason (2002) defines purposive sampling as the selection of groups or categories to study on the basis of their relevance to the research question. The sample chosen satisfied the above definition.

4.8 Ethical considerations

Ethical clearance and approval to conduct this research was provided by the Ethics Committee of The University of The Witwatersrand, Johannesburg (Appendix 1).

This being a qualitative study, interviewees were provided with a clear purpose for the study. All participants consented to being interviewed. The consent included an option for the respondents to withdraw from the interview at any time. All respondents were treated with confidentiality and were not identified in their individual capacities. Where respondents did not wish, for certain responses, to be quoted, their insights were however used to formulate subsequent interview questions and discussions (Appendix 2).

All respondents were only contacted after I had received ethical clearance from the University.

Where secondary data was used, it was in the public domain. Where specific company data was required and had not been in the public domain, it was requested directly from the companies. All company data was handled with the necessary integrity and confidentiality.

Secondary data utilised included annual reports, internet and newspaper articles relevant to the study.

4.9 Confidentiality

The rights of participants to privacy was respected.

4.10 Informed consent

All people participating in the study were informed upfront of the nature of the study and given a choice as to whether to participate or not. They were informed of their right to withdraw from the study at any moment should they wish to do so (Appendix 3).

4.11 Provision of debriefing, counselling and additional information.

Participants were provided with my name and contact details as well as that of the office so that they could contact me, or the office, should they have questions or concerns about the study.

4.12 Conclusion

This chapter has described the research design encompassing the research approach, research strategy and the research methodology taken. Purposive sampling was applied to generate a sufficiently data rich sample size.

Qualitative data analysis was adopted to provide comprehensive insights elicited through structured interviews and observations made.

Research was confined to mines belonging to various mining houses operating in South Africa’s Bushveld Complex. The mines extract layered UG2 tabular ore bodies. The research findings are based on comprehensive and objective analysis of data and conditions prevailing at the operations investigated. The views contained in this report are based on the interpretation of the research participant’s responses. The views are true at the time of the research. To avoid compromising this research, ethical considerations were taken into account as breaches and ethical dilemmas would jeopardise the research field work.

5 FINDINGS OF THE INTERVIEWS

5.1 Introduction

The purpose of the study was to investigate the possibility of mining sustainably in South Africa's Bushveld UG2 narrow tabular orebody by modernising and applying Mechanised Technology. The objectives of this study were:

- Reiterate the need for application of Mechanised Technology in South Africa's Bushveld UG2 narrow tabular orebody.
- Investigate why Mechanised Technology as applied to South Africa's Bushveld UG2 narrow tabular orebody has not always been successful.
- Highlight future benefits from the successful implementation of technology and mechanisation in current operations.

The research method used was discussed in chapter 4.

The process followed to analyse the findings is stated in chapter 4 item 4.5 of this report. The profile of sample interviewed was as per Table 5.1.

The data collected was loaded into computer aided qualitative software, ATLAS.ti 8.

The data was confirmed for relevance and counted with word crucher to generate Word Cloud in Figure 5.1. With this process, the most frequently used words were tabulated for the entire data set and across all interviews.

The data was coded by identifying features in a systematic manner across the data set. All codes are linked to quotations derived from transcripts. They are not filtered. This ensures that each code has evidence. 194 codes were generated.

The 194 codes were organised in consolidated codes also known as sub themes. 41 sub themes were identified. The sub themes were further consolidated into 7 themes which were,

- Technology critical success factors
- Performance of mechanisation versus conventional mining
- Mechanisation and innovation

- Employee role on mechanisation
- Gender transformation
- Health and disease prevalence
- Injury and occupational disease prevalence.

Every theme at the centre of each “mind map” as per figures 5.2 to 5.9 is linked to its sub themes.

The 7 themes developed were analysed and discussed in this report. The analysis formed the basis of the report.

5.2 Quality control of the sample

An overview of the sample was undertaken to validate the details of the transcript. The word cloud was compiled to check the relevance of the interview. The profile for the respondents was tabulated to validate the relevance of the respondents to the topic under discussion.

5.3 Details of the transcripts

- A total of 20 participants were interviewed for this study.
- The total duration time of the interviews - 1270 minutes.
- The average time per interview - 121 minutes.
- The shortest interview - 20 minutes.
- The longest interview - 135 minutes

5.4 Transcription of words through word count

The word cloud shows the words mentioned by the participants during the interviews. The total word count amounted to be 40984 for all twenty interviews. Some of the most dominant words appearing on the cloud are technology, people, mine, and conventional.

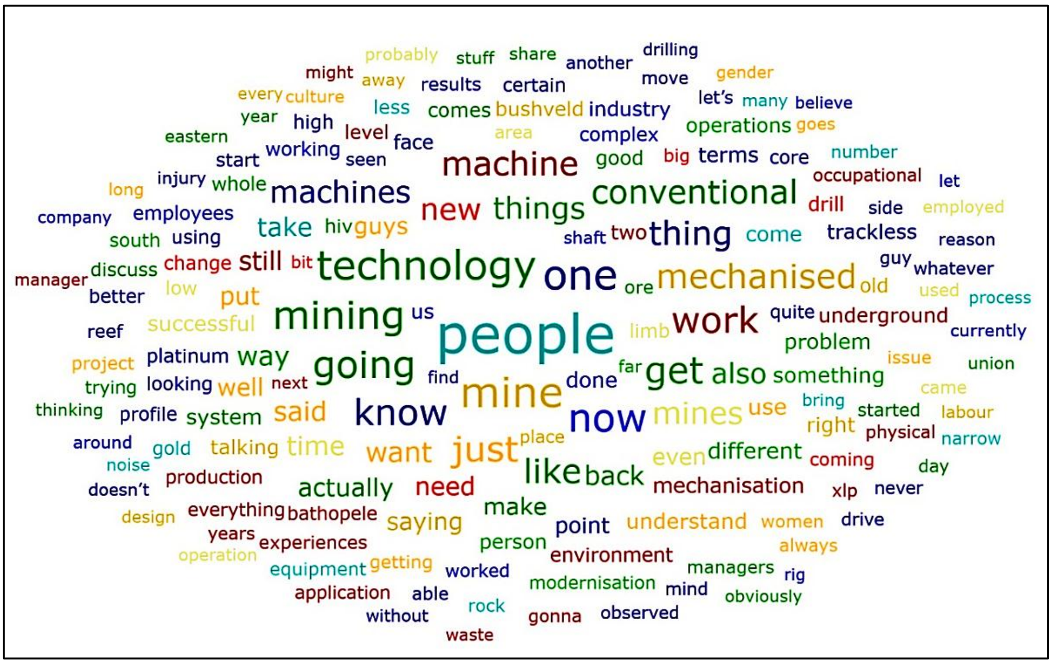


Figure 5.1 Word cloud for content relevance

The edited words relevant for the purpose of the study, resulted in 3108 words. These are provided across the 20 interviews (Figure 5.1).

The five most often mentioned words throughout the interviews were:

- Mines - 532 times
- Machines - 451 times
- Mining - 315 times
- Technology - 299 times
- Conventional - 241 times

5.5 Profile of the participants

The participants were highly experienced within the UG2 Bushveld Complex. Some have worked in both eastern and the western limbs as well as gold mines. Within these participants the majority were working within operations (General Managers, Mine Managers, Mine Overseer, Engineering Manager and Metallurgical Managers). In addition, there were participants within the health space (Occupational Medical Practitioner) and Human Resource Management. In the sample was also an entrepreneur vending within the mining space (Table 5.1).

Profile of Participants							
Key: C – Conventional. M – Mechanised. H – Hybrid.							
PARTICIPANT		**EXPERIENCE**					
Respondent	**Background**	**West Wits**	**West Wits**	**West Limb**	**West Limb**	**West Limb**	**East Limb**
		C	**M**	**C**	**H**	**M**	**M**
RPT1	General Manager Head of Mining Consultant	✓	✓	✓	✓	✓	✓
RPT2	General Manager Group Consulting Mining Engineer	✓		✓	✓	✓	✓
RPT3	Mine Manager Mining Engineer	✓		✓			✓
RPT4	Mineral Resource Manager	✓	✓				✓
RPT5	General Manager	✓			✓	✓	✓
RPT6	Manager Engineering	✓			✓		✓
RPT7	Mine Manager	✓		✓	✓		✓
RPT8	HR Manager			✓		✓	✓
RPT9	Occupational Medical Practitioner	✓				✓	✓
RPT10	Mine Manager			✓		✓	
RPT11	Mine Manager	✓			✓	✓	
RPT12	Mine Manager			✓		✓	
RPT13	Mine Overseer			✓	✓	✓	
RPT14	Mine Overseer			✓		✓	
RPT15	General Manager			✓	✓	✓	
RPT16	Entrepreneur	✓			✓		
RPT17	Group Occupational Medical Manager			✓	✓	✓	✓
RPT18	Section Manager (Not used, recordings missing)	✓	✓			✓	
RPT19	Metallurgical Manager						✓
RPT20	Metallurgical Manager			✓			✓
RPT21 (Accounted for as 1 in Saturation Plot)	Executive Head Technical Services	✓	✓	✓	✓	✓	✓

Table 5.1 Profile of the participants

FINDINGS OF THE STUDY

5.6 Introduction

There is a dominant view in the industry that mechanisation has failed in the mining industry. Discussions with participants indicated that this view is simplistic and that the view fails to appreciate that there are several critical factors which determine the success or failure of mechanisation in mining.

5.7 Theme 1: Technology critical success factors

Figure 5.2 presents the ten critical success factors according to the participants. Each is then discussed in the following paragraphs.

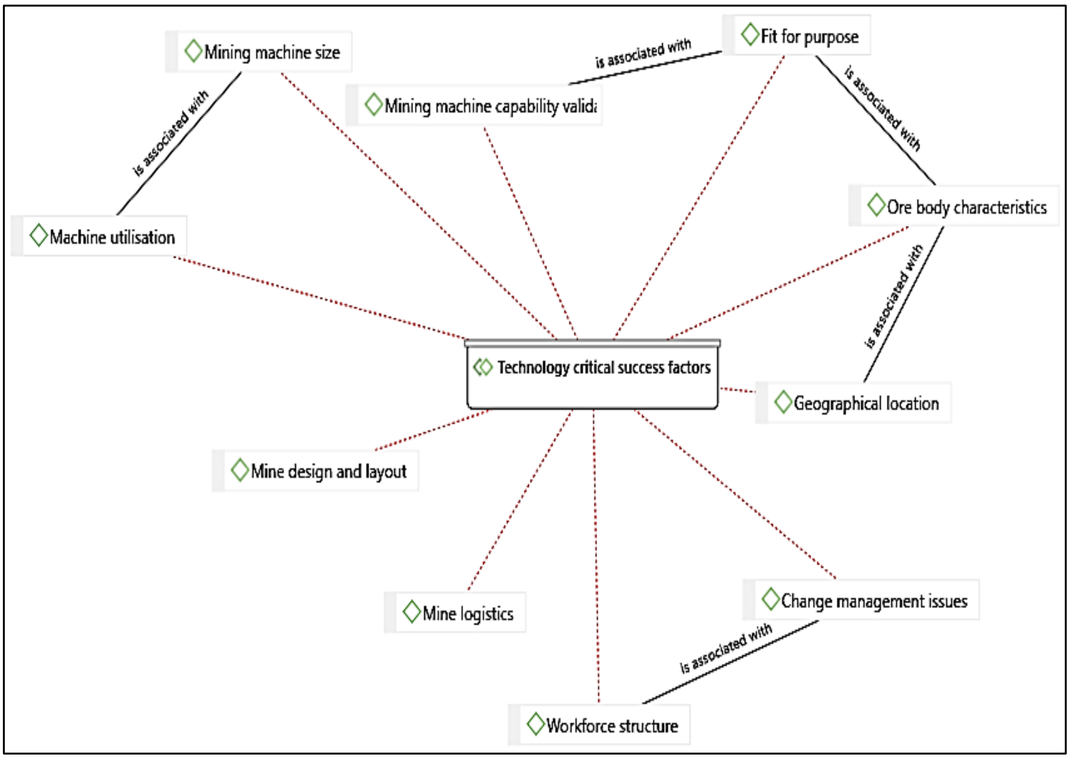


Figure 5.2 Technology critical success factors

Geographical location

Within the PGM producers in a tabular orebody setting as found in Southern Africa, deployment of technology has had mixed outcomes depending on whom you speak to.

Four geographical areas are mentioned by participants. Unki, which exists in Zimbabwe's Great Dyke, has been very successful in the application of

Mechanised Technology. It is in a different jurisdiction and geographical setting than the area with which this report is concerned. It also typically has a wider orebody.

The Western Limb of South Africa's Bushveld Complex has yielded mixed results. Bathopele and Union Mine have produced some of the industry's best practice, while the rest have either shut down or converted back to conventional mining systems.

There is a general belief that mines in the Eastern Limb are successful. This success has however been qualified. Mines north of the Steelpoort fault are not as successful as those south of the fault.

There are pockets of excellence in the various geographical locations. The evidence given by this research demonstrates there are other elements within these success factors which must be considered and addressed for the operation to be successful. Examples by Oberthur & Melcher(2005) are the failures of the Old Wedza Mine (1926 to 1928) close to the current successful Mimosa Mine in the Great Dyke. They also report the failure of Hartley Patinum (1997 to 1999) next to the currently successful Zimplats Ngezi Mine, again in the same geological Great Dyke locality. Reasons here are given as metallurgical.

While operations may be in the same geographical area, the geology may be different. This results in a different performance outcome.

According to respondent 5, the Steelpoort fault in the Eastern Limb is proving to be the dividing line for the successful southern mines compared to northern mines. The difference has been attributed to differences in geology, which in turn is impacting on the economics of the much narrower reefs north of the Steelpoort fault.

"I would say an overarching statement saying … those are the main factors. It can be your geographical location but they are all in the same area, except for Unki…they are all in the Bushveld. The access is pretty much the same." RTP1

"The Eastern Limb is not a success story and there is a fundamental denominator with it. It's called the Steelpoort fault. If you look at the Eastern Limb, you have north of the Steelpoort fault and you have south of the Steelpoort fault. North of the Steelpoort fault is your dogs, which is Morula, which is a platinum mine, which is Modikwa, there is Bokoni, and there is Smokey Hills." RPT 5

Orebody characteristics

This theme came out strongly among participants as a characteristic fundamental in the design, mining method selections, technology application and overall resourcing of a mining enterprise.

Material characteristics of an orebody include:

- Width
- Dip
- Regularity
- Planarity
- Overall dimension
- Amount of metal contained in the rock.

"What is the biggest challenge with a narrow tabular orebody? It's the geometry of the orebody, number 1. Because you have these pieces of equipment that do not go in everywhere, because you have to keep them [excavations] as narrow as possible or as low as possible and they come and they get stuck on the floor or they get stuck on the hanging wall." RTP2

"Industry has elected to adapt available mining equipment and technology to use in the narrow conditions. Global mines are not soft rock, but they are generally not as tough as what we are dealing with here." RPT1

"There is no one size fits all system for the mining system because of the orebody which dictates what you require and what you can use. There is no universal solution to the variable reef configuration (geometry) in the Bushveld UG2. Therefore, there can never be a single solution to the diverse geometries encountered." RPT2

"The rock is very hard. The rock is narrow by global mining standards and also generally, it gets deep rapidly. It's not flat like the coal mines. And there is the dip issues in many cases, which makes the introduction of mechanisation more difficult." RPT1

"We forget that the orebody is dipping at 18 degrees. We forget that the orebody is narrow tabular and we are stubborn in the sense in terms of decision makers at a certain level." RTP5

"Doesn't allow for the fact that not all ore bodies are mechanisable because of the geometry of the orebody. Coupled with the geometry, grade distribution, coupled with the fact that you put all these into one working system and the system has to be functional." RTP21

Orebody characteristics have been the major difference between the mines north and south of the Steelpoort fault. Union Mine, because of its 20 degree dip had to settle for a hybrid mining method after experimenting with the room and pillar mining method. Because dip was considered in the final designs, Union Mine was successful.

Mine design and layout

There was agreement that Mine Design is influenced by the orebody characteristics. There was also agreement that mines designed and commissioned as mechanised operations had a chance of being successful. Some of the problems of mechanised operations on the Western Limb have been attributed to this change mid-mine life.

> "My first reason would be the design. If the mine has been designed from the beginning with long haulages, and then later on after the haulage has advanced a kilometre, with locos and rails and winches, and later on you would like to change to mechanised, where you have to install the belts, it is normally problematic. Whereas, on the Western Limb, the mines which started recently, that have started with the intention to go mechanised like Bathopele." **RTP3**
>
> "The trouble in mining is you just can't go back. Lonmin had this problem." **RPT1**

It is important to develop a robust mine Extraction Strategy covering the entire mining lease area, unconstrained by time, during the concept and feasibility study stage of a greenfield project. This strategy is informed by orebody characteristics which include among others, physical, geotechnical and economic factors. This strategy informs layouts and designs. Smith (2012) makes the same observation.

Participants stated that operations managers are asked to deliver into plans that are not achievable. However, development of credible investment proposals, which are informed by the above, gives operational managers a fair chance to meet and beat targets.

Mine logistics

Participants agreed the logistics of a mechanised operation are essential for success. Logistics are those activities, tools and infrastructure supporting the primary rock breaking activities.

> "We need to look at the logistical arrangement. Belt arrangements. Bathopele, should have had a chairlift. That's actually an interesting observation because… the wisdom of saying because you are trackless you can put man transporters, those things are horrible. A chairlift actually can go service departments, supervisors. Anybody is transported close to the working area without having to drive up and down which is an expensive option. Walking up and down is an inefficient option. So you could put in here in your comparison, how do people go down? Is it a chairlift or is it man carriers and you can put yes, no, yes, no, yes, no." **RTP1**
>
> "The second thing is, your logistical arrangements must be in place. Refuel, oil and men movement. Chairlifts for example. You need the best belt load on facility from scratch. In other words, vibrating feeders. You should deploy graders basically from start. Other people will argue that one needs to have provision for road building material. It must be available. If you are unable to put those things into place, then don't go ahead." **RTP1**

For a mining operation to be effective, the movement of men, material and rock must be seamless. When they get in the way of each other, the operation becomes ineffective. To enhance face time, employees must be transported to the face in minimum time. Rock movement should be such that the mining cycle is supported and maintained. Material must be available at all times so that people can perform their work. Logistics provides an enabling environment for the operations to perform effectively.

No mechanised operation should commence without maintenance workshops, refuelling and lubrication facilities, as well as support auxiliary vehicles. These are the life blood of the production fleet.

Mining machine capability validation

The participants highlighted a critical success factor - mining machine capability validation. Their view was that not enough is done by the mining houses to ensure compatibility between the procured machines, the design and the geotechnical requirement of the South African tabular UG2 mineralisation in the Bushveld Complex. This has resulted in machines being incapable of performing the job. An inordinate amount of time is being spent in making changes and variations to adapt the purchased machines to local conditions. This decreases the resonance in the uptake of mechanisation in the mines.

"We put the machine without any processes that accompany it. We deploy machines without thinking. We must ask, what is the process of rolling it out in a structured way? An OEM will come and will claim all these benefits and the manager in office will just think, by this machine just being underground, within a certain time, we will start reaping the benefits...not realising that there is a certain channel that needs to be followed for you to realise those benefits." **RTP 7**

"We tend to bring those machines because it's a mine and its mechanised. The OEMs don't real come and study the environment. To me, you will always fall short of the delivery of the results that you need to achieve." **RTP10**

"There is failure by OEM and the company that is a manufacturer of the machine to sell the product properly. To design the product properly, so that it suits the South African mining industry." **RTP16**

Mining houses and OEMs have been cooperating in various ways to develop products which are effective in the Bushveld. Results have been varied.

The Bushveld Complex is unique. Therefore, it will require unique solutions, developed together with people who understand the complexities and requirement of the orebody. The technical complexities are well understood. Developing the way forward requires sustained and coordinated Research and Development, which industry and government should take over from individual mining houses.

In the meantime, mining houses must continue with the current procurement and modification of products available. OEMs need to improve the quality of service by relocating their manufacturing facilities. They must reduce lead times in procurement, repairs and modification of production units. OEM must be seen to be part of the production team, sharing in the successes and failures of their product.

Fit-for-purpose

Participants agreed technology was not always fit-for-purpose. The implications of this gap have resulted in technology not operating at optimal levels, increased costs and general inefficiencies. This has called for continuous improvement and reworks on the supplied machines. In Total Quality Management rework constitutes waste.

> "Because of the undulations of the reef, we have gone from a double boom to single boom rig so as to make drilling easier. The biggest issue now is to bolt at 1.9m when the reef band is only 0.9 to1m." **RTP 4**
>
> "A machine fitted with brakes to stop it when close to people is not suitable in a mine full of people. When introduced in the workplace, this machine is gonna keep on activating the brakes. In a day brakes will be activated 60% of the time. Then what's going to happen? You are gonna start having high maintenance cost on your braking system. Is it fit-for-purpose, that's where the question comes in. Then you end up with people bypassing that system." **RTP6**

All participants understood the uniqueness of the Bushveld Complex. It was also important they understood what is currently on the shelves is not likely to be fit-for-purpose.

There is a need for strengthened collaboration with OEMs to continue with the current on-going modification. Research and Development must continue, but elevated to industry and government level.

Mining machine size

Respondent 21 spoke of applying technology in an enabling environment. An enabling environment is created in the designs, effective procurement and a work environment which allows people to willingly work. The observation by Respondent 1 complements observation by Respondent 21.

> "Then there is the machinery sizes. Are we using the right size of machinery? Is the 777 machine the right size of machine or is it too small? Who is using hand drills to perform certain tasks? Is it an advantage or a disadvantage? On belt loading, should we have vibrating or no vibrating feeders? Vibrating feeders give the best results but not everybody is using them." [RTP1]

Mine design, infrastructure determination and procurement is a key management performance function. These issues are addressed in the feasibility stage when investment proposals are developed. Machines procured must be fit-for-purpose. The entire mining value chain must be interrogated, and identified shortfalls addressed.

Mining machine utilisation measurement

The participants agreed there is a need to measure performance matrices of mining machines. Various matrices are used to measure machine performances, of which utilisation is but one of many.

"The next big one would be the working hours. The actual face hours. The next big one would be your machinery management. In other words, servicing, availability and utilisation. I agree with everybody when they talk about machine availability. It also important to know that if the machine is available, it must be used. It must be doing hard work at the face." RTP1

"What the studies also say is that you will pick up the utilisation of the machines. They do not want to work machines to destruction. It comes back to the thing I said about the conventional mine overseer." RTP2

While the participants agreed shift availability of plant and machinery is a relevant metric, the computation of Overall Equipment Effectiveness has become a more prudent manner of measuring and tracking their performance. OEE not only tracks utilisation, but plant performance as influenced by its design and compatibility with the work environment, and the environment in which plant operates. It also tracks the operator's performance as influenced by the physical environment that the operator works in, the operator's skill levels, and the availability of an enabling work environment.

These elements of OEE have not been well understood and managed. Currently, there is a real effort by mining houses to apply statistical controls to manage plant and machinery. Base metals and open pit mines are in the forefront of this.

Workforce structure

Workforce structure is the generic home for all work force related issues. In the word cloud it appeared as "PEOPLE". In it, the role of Unions and perceptions of the workforce in relation to technology application, among others, are investigated. The participants indicated that shift arrangements, as they interplay with the desired production output, were a critical factor in the application of mechanisation and technology.

"Number 2 is the norms or the way the labour force is structured. The Unions, are trying to protect jobs. So, once you are already on conventional mine, to change to mechanised, you face greater resistance. Far greater resistance unless if you start a new mine at the Western Limb and get rid of all the old technologies and appoint managers that have already adopted the new way of doing things it makes life easier." **RTP3**

"The people that are supposed to use the technology do not accept the technology. There is a resistance to accept the technology. And then there are peoples' perception when it comes technology, particularly in South Africa. It's that it is coming in to replace the labour force, of taking away jobs of people." **RTP16**

"Also the shifts worked are an issue. The Bathopeles of this world have modified their shifts. But you are still trapped inside an ESF (Eleven Shift Fortnight). On trackless mines it needs to be better. Do you work 3 eight hour shifts or 2 ten hour shifts or 2 twelve hour shifts? Do you blast once or twice a day? Because I found that to blast twice a day is more efficient." **RTP1**

"Even here in this valley we work differently. Two Rivers is doing (CONOPS) Continuous Operations. We don't do that and Mototolo has got three shifts, we've got two shifts. So even in this valley we're doing different things. You need to find out which is the best." **RPT4**

"There was a very pro-mechanisation or trackless sentiment and that whole approach and way of thinking was for me instrumental in making the thing a success because our approach was based on... we will make it a success and we will optimise it until it is a success. Thinking was that it cannot fail, it may not fail. Failure was not an option." **RPT5**

Effective shift length is partly influenced by shift change overs. Reducing shift change overs by working fewer, longer shifts helps this cause. CONOPS facilitates the continuous utilisation of assets. All these add up to the overall profitability of the business.

This cannot be achieved in an adversarial environment. Modernisation must be seen by all stake holders as means to enhance and improve the quality of work life of all employees.

Change management issues

There is an overlap in Workforce Structures and Change Management. They both have a people element.

There was a common agreement on the need to manage change. It creates the acceptance by the workforce of new workplace designs and methods. This creates ownership and sustainability.

"But there is still a resistance to change. It's not only from a managerial point of view or not invented here syndrome, but also, you got to contend with your workforce." **RTP2**

"The fourth thing is Technology, Process, Systems, then it's the People. What is my Change Management? As I am saying, we almost discarded a machine thinking that the machine is a failure. In the mean time I had modification done on the machine but we did not communicate it right. So, in terms of people, what feeds into my lesson plans? What are the new Risk Assessments that I must do? Do my people know the new work methodologies that accompany those processes and the system? And how do I keep on refreshing them?" **RPT7**

The older workforce employed on the Bushveld comes with the burden of conventional mining. This includes managers and supervisors. Retraining, reskilling, and communication are change management initiatives necessary for the successful implementation of modernisation. The workforce must be part of identifying and developing solutions. If change is to be successful, all the stake holders need to be part of the journey.

New generation miners come with no burden; mechanisation is the only thing they know. It is therefore imperative that full suites of Mechanised Technology, capable of completing a mining cycle, are procured and made available at all times. Discourage people from defaulting to conventional thinking and work methods by, among others, replacing pinch bar with a scaler, or upskill operators to be able to rattle the face with a drill rig.

In summary, it was clear there were a lot of factors influencing the technology performance in mining.

5.8 Theme 2: Performance of mechanisation vs. conventional

While the question of mechanised mining methods' performance, relative to conventional mining methods, was not specifically asked, insights about it were provided by the participants.

The superior performance offered by mechanised mining technology prompted this surge in the uptake of the technology in the Western Limb, and subsequently in the Eastern Limb. The demonstrated superior performance of the technology in pioneering mines marketed the technology.

"In mechanised mines, you can have far more superior results, have higher efficiencies. You can produce and deliver greater outputs per man employed at mechanised mines as compared to the conventional mines. Comparing LHDs that have been employed versus the winches at the conventional mines, the difference is great." **RTP3**

“In Rustenburg area specifically, it proved to be very successful when they started. Then, Impala latched onto 14 Shaft which was a Merensky Section that they trialled, and because of the successes at Bathopele, they wanted to see if they could do exactly the same thing on a Merensky reef horizon on 14 shaft. Aquarius’ Kroondal, chrome had not started at that point yet, it only came in afterwards. In that time frame, XXX became the CEO of YYY. XXX had some background pertaining to Zimbabwe and other commodities trackless set up. He launched a campaign to convert YYY to a mechanised methodology. At that time, the only other mine that was doing successful trackless mining was the old Union Declines, the high profile section. There was no low profile as yet and Modikwa did not exist.” [RPT5]

“If you look at 2001, Union was a dog and Union had to do something different. In a sense you were almost funnelled into a different way of thinking and I am making this point because it will validate what I am going to say on the next point.” [RPT5]

“If you go mechanised or trackless, you will access your orebody quickly. As compared to a person who goes on the old conventional mining, we reached our steady state last year and this year we exceeded our steady state by almost 120 - 140% because of this mechanised set up. The mine was started in 2010/2011.” [RPT6]

“Let’s talk about a tabular orebody. I think the success of this is really on Room and Pillar. There are a lot of mines around here that are doing exceptionally well. There are mines that are doing between 2 400 and 3 000 squares with 1 team and1 suite of low profile equipment of.” [RTP7]

“There has been a significant modernisation and differences in the ways of doing work which has allowed the business to remain competitive over time. But the fact that not all operations have introduced trackless drilling units does not mean that they haven’t mechanised.” [RTP21]

Trackless mechanised mining is an attractive option to apply to an operation. The benefits are there to be seen. Success factors must be attended to upfront if full benefit is to be realised.

5.9 Theme 3: Mechanisation and innovations

Innovations

There is a view within the mining industry, both domestic and abroad, that South Africa has lagged behind with innovation, while the rest of the world has made significant progress.

Global mining has made tremendous in-roads and breakthroughs in innovating how mining is conducted in their jurisdictions. In settings similar to other jurisdictions, South Africa has adopted their best practices. Where local conditions have been unique, like in the narrow tabular hard rock conditions, South Africa has continued to experiment and seek alternatives means of breaking rock at the face.

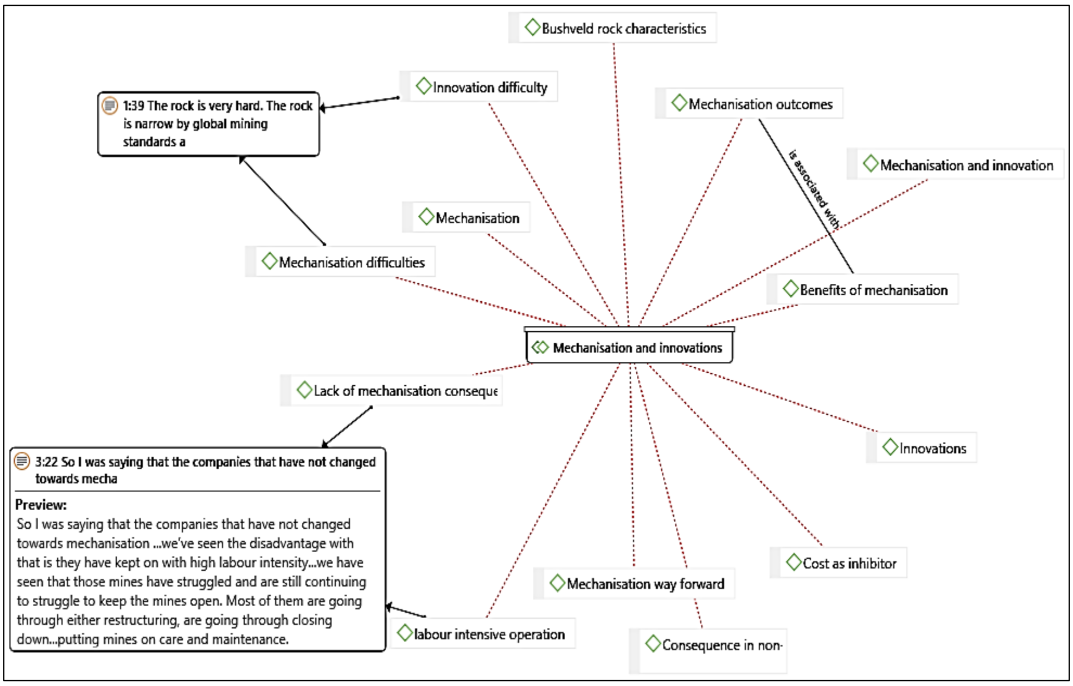


Figure 5.3 Mechanisation and Innovation

Some participants are of the view that instead of worrying about reducing waste generated underground, innovative ways of treating the generated waste on surface should be pursued.

"The global trackless experience did not cover the needs of these ore bodies. That is narrow tabular hard rock ore bodies. Machines were not readily available for this. And for decades, much, much effort, time and cost was put into developing systems to do it. Examples are rock cutting, high pressure jets with resin material. There has been diamond wire cutting, there has been parallel raise borers to drill the reef out." **RPT1**

"Exactly. I am saying machines should be optimised. A machine should not be new. I am saying, bringing in machines should be evolutionary, and what I mean with that is it has to happen with a journey over a certain time frame, a systematic journey through time and should include systems.

So, what brings evolution about?" **RPT5**

"There is a block that we will have to open up between 2019 and 2021, provided we are getting the block from Der Brochen in 3 North. Because we want fast development I actually thought that we would use a tunnel borer for developing that decline there. If we are not going to roll out that tunnel borer in a system way, that tunnel borer will not give us what we want." **RPT7**

"We tend to try to stay in line with the trends of the industry, like if the trend is to go to XLP, then we have to go there as well. But it's not necessarily to say that that's the proven method. There is maybe something else like a DMS plant which could have assisted much more than only in one section XLP fleet." **RPT13**

"The mine has opted for a metallurgical solution. The commissioned Dense Media Separation Plant is working. Out of a plant throughput of 200 000t per month, Dense Media Separation plant is designed to remove 20% waste. Currently it is separating12.5%. The design operating unit cost will be achieved once the required separation rates are achieved." **RPT19**

While there have been significant innovations in the sequential drill, blast, clean and support mining environment, the initiatives, together with the continuous improvements, have moved this industry forward.

There is a need to increase innovative metallurgical processes to address some of the issues the miners are attempting to eliminate underground. A good example of this is dilution caused by narrow channel widths. Ore sorting and separation techniques must be pursued by the metallurgical fraternity so that waste in the reef can be removed before starting the comminution process.

Mechanisation

Mechanisation, modernisation and automation has successfully been applied to South African Mining. Mechanisation challenges have been in the hard rock narrow tabular orebody environment. The technology has been well received and applied in South Africa’s base metal and chrome mines. However, the lack of economic success in certain applications has resulted in the technology not being the preferred method of winning minerals in all applications.

“The introduction of mechanised methods into the South African hard rock mining industry is not be underestimated. In other words, the problems, the difficulties.” **RPT1**

“Why is Two Rivers successful, have you ever asked yourself that other than that we have a good orebody and all those things? In terms of technology we re-built and redefined a lot of the machines we get. The Sandvik guys, a lot of the technology they are building their machine on, is what we have said...do...don’t...don’t...don’t...change and all those things.” **RPT10**

“I would say, if I had to design a mine now, I would go with abandoning the old technology and look at new technology completely. Go all out, especially in the Eastern Limb. Look at all the mines that have moved away from the conventional way of doing things. You will find that the entire value chain has been mostly automated. The innovation that is there is far superior and produces far more superior results as well." RTP3

Mechanisation and Innovation

Innovative combinations are on the rise. For a long time, mechanised mining methods have been associated with trucking broken rock to surface. By adapting best practices from coal mining, successful belt application on hard rock mines has replaced dump trucks as a means of transporting rock over long distances from underground to the surface. There was evidence of wide-spread application of this innovative way of moving rock on the participating mines during the study.

Innovation and optimisation of designs, in terms of equipment and layouts, is continuing as operations are continuously learning and adopting industry best practices.

"Changing systems e.g. dip belts, from the old way and having belts which are less labour intensive with less maintenance and having the machines, I am talking about LHDs instead of winches and locos." RPT3

"We have a group of roboticists at the moment working on extraction units which are autonomous that are about the size of a large pelican case. 600cm wide by 400 cm high by 900cm in length. They mine UG2 at what we call on a laughable scale. It's like they are chiselling and chipping off little chips of UG2. But they do it continuously, 24 hrs. Taking off small quantities over a long time. The concept of large volumes continuously but in very small measures instead of taking 100t blasts, we are taking 100gram chips but just continuously. The prototypes should be ready for trial by end of next year actually. So it really a whole different way of looking at things." RTP21

Benefits of mechanisation

There is agreement on the need for mechanisation. Benefits and outcomes derived from mechanisation are both measurable and quantifiable.

"So, I tend to think that it's not about just buying a machine and trying to get rid of the people. It's to be realistic. We have seen that the platinum prices have dropped and stayed where they are. Mines that have continuously been operating with high labour intensity have continuously and still are under pressure in terms of the cost to produce per platinum ounce than ones that are currently operating with less labour with more sophisticated machines." **RPT3**

"Mechanisation and New Technology will enable these guys to function optimally because the work is less dependent on your physical strength but more on your mental strength and capabilities. Obviously with mechanisation, because of the nature of the machines we use, your psycho motor abilities play a crucial role. So, a mechanised environment is really the one place where we believe that we can increase the number of women participation. Two Rivers has about just over 20% of its workforce being women, of which about 15.5% are in core production. I honestly think that technology and mechanisation will definitely facilitate the achievement of workplace gender transformation and it will accommodate those, and not only employees suffering from HIV, but also those that are either injured in the workplace and to a certain extent people with disabilities. I think this is the one place where we might be able to see much greater transformation of the workplace as compared to what we know on conventional mines." **RPT 8**

"There are two worlds. The managers of the operation here in the Bushveld have seen the benefits because of the responsibility that lies upon them in terms of the legalities when people are injured and all those things. We, as managers, we tend to want to go to an environment where you have got less and less people because of the way the law is changing in terms of holding managers accountable. So, we want to move away from an environment where it is labour intensive to where there are more machines working. And not only because of that, because of issues of labour unrest and all those things. You want few of those in your life. Cost is another issue. Labour is an unwanted cost and it is open ended. We tend to want mechanisation to succeed because of those reasons.” RPT10

Technology and mechanisation is constantly coming across as the way to move this industry forward. Not only is it good for profitability and employee health and safety, but it also is enhancing the quality of life for the manager in the office.

Lack of mechanisation consequences

Lack of mechanisation and the slow rate of adoption has left us where we are. With the ever increasing cost of production due to inflation, increasing labour costs, and increased demands on the health and safety of employees, non - mechanisation will affect business sustainability.

“So, I was saying that the companies that have not changed towards mechanisation, have carried on with high labour intensity. We have seen that those mines have struggled and are still continuing to struggle to keep the mines open. Most of them are going through either restructuring or are closing down. The mines are being placed on care and maintenance.” RPT3

“In the several occasions that I go underground, I would observe a situation where I would look at the height of the person. You look at the height of the hanging wall and you say, there is no way that you will be able to effectively bar. Just the weight of the piece of metal at some stage, you are going to get tired and you are going to do it because your supervisor says you must do it. But are you doing it diligently and in the right way? I agree with you 100% there is definitely a new conversation that needs to happen. To say if we want to truly remove people from those danger areas, we have to say, what else is still conventional in a mechanised environment and remove that which is conventional and mechanise it. People have been barring rocks onto themselves on this operation. Our people are working hard towards finding ways and means to modernise, to make it better and to make it safer. I don't think we can ever say that we have arrived. There is going to be that continuous improvement as and when technology improves." **RPT8**

Mechanisation difficulties

One of the biggest obstacles to developing fit-for-purpose mechanisation technology is the manufacturers' location. Usually on a different continent. The engineers designing these machines have no appreciation of the local conditions.

When modifications are required on the machines, as is always the case, both expertise and facilities for the execution of the changes are overseas. This results in excessive time being taken to execute changes and modification that may even be minor in nature.

"If this thing is manufactured here, you get all those engineers, the designers and everything and you say, here...what's happening? Then it becomes easy to learn and understand and all those things. The people designing the machines do not understand the conditions. They are sitting there. You need these people to be here to understand the conditions so they can see while designing and modifying." **RPT10**

Mechanisation, the way forward

Like all the innovation initiatives of the past, technology and machines, which are suitable and adaptable to the local South African conditions, must be developed. In the absence of such discoveries, modification of current known technology must continue to be adapted for local conditions and use.

> "Eventually the most plausible way forward was to take the technology that was available and modify it for the narrow conditions, and that is what was done, but it is still a learning process. It has not been economically feasible and that is due to, let's say, cheap labour and the falling rand, low cost of the input commodities, the explosives, the old explosives, the accessories and the timber for support." **RPT1**

The sentiments expressed by Respondent 1, above, were common among the participants. These views were expressed as some of the reasons why mining companies sometimes considered reverting back to conventional mining methods.

Cost as inhibitor

The economics of mechanisation has always been a part of the decision on whether to adopt technology or discontinue its use. One of the major elements influencing the decision makers is costs.

> "A lot of that was done, but there has also been the use of the impact ripper and also oscillating disc cutters. The impact rippers are as applied to the coal mines. They were manufactured in the 60s and the 70s in the Anglo Mines. So I am gonna come to something but while we are trying those thoughts, there is a thing called a Stomec, Atlas Copco. It is an electro hydraulic stope drill rig. It ran on tracks. Way back. That's in the 70s, sorry in the 80s. So, why did these things not work? It's because of the very high costs of the mechanised equipment. Especially the rock cutting relative to drilling and blasting, especially with the old explosives technology. The newer explosives technology is costing a lot more." **RPT1**
>
> "I think to me, I will give it a context of the South African economy. Currently, it is much cheaper to import than to develop. There is a tendency to import rather

than develop and manufacture. I will give you a good example, I came here and I said to the guys, we are using flexi bolts. I said to the guys, now I want this thing to be automated. I told the XXX guys, where do you think XXX went and redesigned this machine? There, in Sweden. They brought it here, developed, 2 months later they said this machine, there is still a lot of work that we needed to do. What did they do? They too it back to Sweden." **RPT10**

"We have spoken about the rigidity of the mining industry, and I think the drive towards using machines has been driven by safety imperatives. To try and remove people away from the active advancing face and yes to a certain extent to try and bring about improvement in terms of efficiencies, because whoever is selling the technology, they will sell it on those three fronts; safety, productivity, costs. But, you will not be told how. Ultimately, this technology becomes so expensive that it is just unbearable. I have tried to using these XXX machines. And they would bring mechanics with the unit just to come and fix the machine and the breakdowns are so overwhelmingly high that your cost associated with the maintenance on the machine actual supersedes the benefits of having that machine on board." **RPT11**

The benefits of technology and mechanisation are not called into question. The cost of procuring the fleet and any spares required from overseas, in foreign currency, and maintaining and operating the fleet, is the reason why mining companies are constantly considering reverting back to conventional mining methods. This consideration is increased when economic cycles are not favourable to the South African importer. It would be a different matter if the equipment was locally manufactured.

Consequence of non-mechanisation

Non-mechanisation means we simply carry on as before and hope that business will somehow continue to survive in the face of increased labour costs, inflation and an increasingly educated labour force.

“On the conventional mines, HIV sufferers were covered by their buddies and were walking dead underground. The sufferers on this mechanised mine looked after themselves and then they had the machines doing half the job anyway.” **RPT2**

“Conventional methods continue to have higher labour intensity, and those that have moved forward to mechanisation and brought in more sophisticated machines are producing platinum ounces at far less costs than their conventional counterparts.” **RPT3**

Non-mechanisation is therefore not an option. Failure of the industry to effectively respond to the demands of the business environment will kill it. Organisation will be driven out of business by the high costs of conventional production, challenging geotechnical conditions, societal demands for safety and a population disinterested in the dirty manual work associated with conventional production.

5.10 Theme 4: Employee role on mechanisation

People in an enabled environment are a prerequisite for the successful application of Mechanised Technology. An enabling environment is created by effective work designs. Synergy is created between people, technology, processes. The physical environment where employees and machine have to operate in must support safe high-tempo production. People must be trained, fairly remunerated and be willing to pursue organisational goals. Machines and mineable face length must be available to sustain the continuous mining cycle. Managers must ensure the above are maintained at all times so that workers can willingly discharge of their contractual obligations.

"I think employees have contributed big because if you look at where the mine was ten years ago. You look at where they are now in terms of production efficiencies, in terms of injury rates. All that has been improving year after year. It took employees of UG2 to buy in into the idea of modernisation and to embrace innovation. They looked at mechanisation as something that could assist each and every employee and employees' managers and employers to ensure that they achieved the best results out of that modernisation." RPT3

"I will say that it is because of those employees and their managers and their employers. It is because of them why this modernisation has actually worked and it is continuing. It is continuing to bring even far greater and better results than ever before. They contributed positively towards the success of modernisation." RPT3

"I think we have contributed quite a lot. And we are still continuing to contribute. And I will tell you why I say that. If you look at the technology that is being trialled, in terms of mechanised equipment, there is a lot of us in this valley that are contributing towards that. For example, we are busy piloting the fully automated bolter." RPT8

Employees are stake holders who must participate in identifying, developing and improving the way we work.

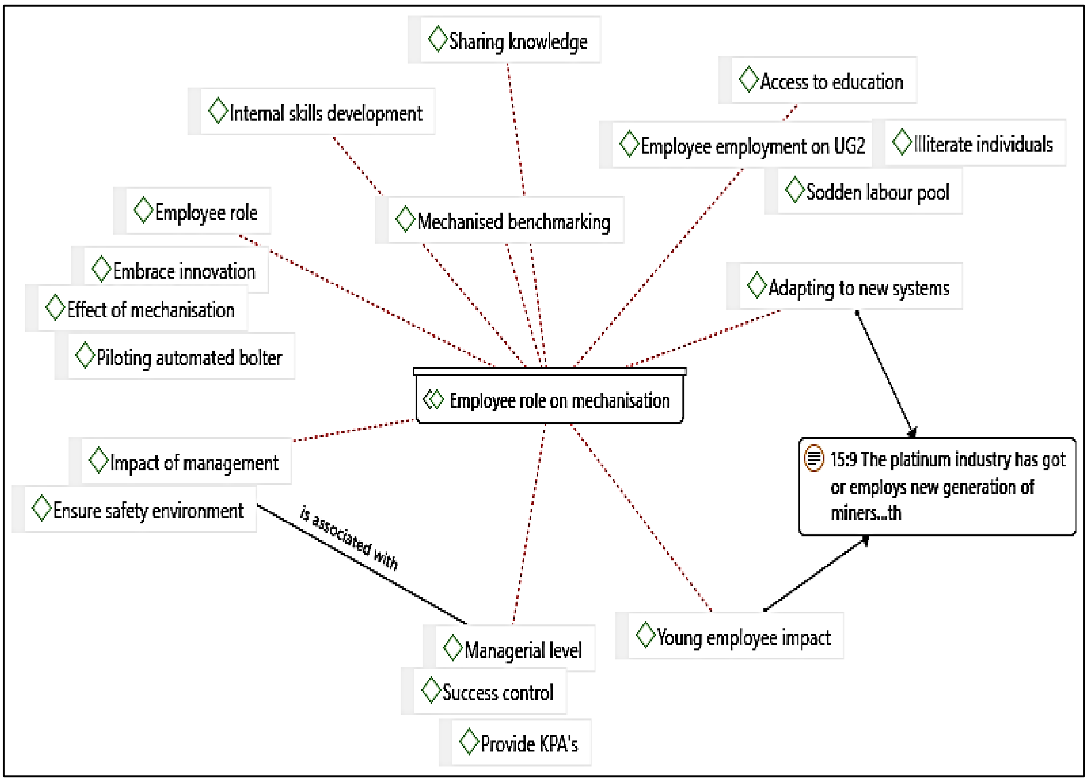


Figure 5.4 Employee role on mechanisation

Managerial level

Management develops and defines the strategy an organisation pursues. They provide the guidance and leadership required to achieve its strategic goals. Management must create an enabling environment if mechanisation is to be successful.

"When I was studying the investment proposal, design was 240 000t at 3.2g/t. I went to XXX and I said to him, this plan, we will not build that up. Perhaps later on into the future. Right now**….the investment proposal is flawed, it's too steep."** RPT2

"I think one thing that we have done as the mining industry is that we have been at times been **overly ambitious...in what we want to do...and we have fallen into the trap of over promising and under delivering**, sometimes as a result of what we say out the in the media. I suppose the media, the investors, and the analysts. If I just look back at the XXX era...there would be an announcement made to say, we are going to produce 3.4million ounces in this year...but then we go and do reverse engineering of how we are going to get to the 3.4million ounces instead of saying, well let's understand what can a particular operation do. What is your potential and capacity and then we can consolidate back to say, this is the number." RPT8

"**If you do an analysis of what were the three things that…not failed but were markedly different to what we expected between our investment proposals a**nd our completed projects and the three were basically **your ramp up rate, your operating cost, and your head grade**. So all three of those were **too optimistic**. So the ramp up rate was too fast relative to what was actually achieved, and in hind sight, **when you do a calibration the ramp up rate across virtually all the projects that we delivered was consistent but every time we put a project through for approval we accelerated the ramp up rate, perhaps to make the project more attractive.** In term of operating cost, we invariably underestimated the operating costs because of that issue related to the relative performance of the equipment. So the performance of the equipment was less than expected. So let's rephrase that…so the performance of the equipment which drove the accelerated ramp up rate, **the actual performance which was the reality of the ramp up rate is less than was expected. So your unit cost goes up** and the third is the **head grade.** We invariably did not allow adequately for **the dilution**. The grade estimate, was spot on, but the dilution was always an issue. It was incorrectly estimated. Again too optimistic.

But the scheduling which relates to the performance of the mining is optimistic. Why that happens is really the question. Is it because we do not want the projects to fail, is because it's self-delusion or is it because we do not have other projects?" RPT21

(Author: Emphasis is my own.)

Investment Proposals presented to the executives for project approval must be realistic and achievable. Operational managers have a responsibility towards both their employers and employees. It is their responsibility to ensure that designs and assumptions made in generating the models are based on sound management and technical principles.

Impact of management

Other than defining organisational strategies, executives must provide their line functions with the means to execute organisational strategies. This includes, among others, such resources as appropriate and serviceable machines, spares and a means to develop a workforce that can deliver on the strategic imperatives.

Other participants felt senior managers were not diligent when making the strategic move to Mechanised Technology.

"All these successful managers understand what needs to be the outcome and what is required here. And if that level understands that, the "oke" (person) underneath is enabled to perform accordingly because he gets KPA's and he gets taught how and the knowledge and the right equipment and availabilities and so on and so forth." [RPT2]

"There was a managerial change and an engineering change and that same drive and that same buy in was not there. There was no appetite. There was not the same appetite. So they moved along. The OEM just lost, everybody lost and eventual they pulled the plug. The CEO pulled the plug on the thing." [RPT2]

"In deploying machines to deal with problems, what I have experienced in the past is, it comes with the leadership in that era. If that is their flavour then they will drive it. Sometimes they make a name out of it, name and fame and whatever and then it's never implemented or never succeeding and once they leave, those things get chucked out and say...that's it. And maybe we tend to be too easy following the trends of the industry.” RPT13

“This low profile drill rig is the machine to produce and push the production. They set a certain amount of target or a certain amount of square metres to be blasted with that machine. That machine fails to drill, then everything turns around. It doesn’t become the machine anymore; it becomes a person. Instead of developing systems to be able to address the problems we want to force technology into that whole situation. We force in technology that has not even been trialled and tested.” RPT16

Converting from a conventional to a mechanised mining system is a strategic decision which should be initiated at a group level. It should be the strategy of the company and not an individual. The strategy should be of such a robust nature that it outlives individuals within the organisation. Roles, responsibilities and performance measures of OEMs and mine operational staff should be defined and signed off up front.

Mechanised benchmarking

In the hard rock tabular orebody environment in the South African Bushveld, the industry has had to develop and modify tools, equipment and technology as they go along. They have had to constantly measure, calibrate and recalibrate their performance against their peers within the same constrained environment.

The participants are proud of learning and growing together with their peers. This was particularly evident in the Eastern Limb.

“To be honest, one of the main things that I picked up here, in terms of on the Bushveld is the benchmarking, mechanised benchmarking. What has happened is the contributing factors. You’ll always find that Booysendal will go and benchmark with Mototolo in terms of how they are being successful in using the LHDs. That has been the benchmarking in this area because all the mines in this mechanised mining they can easily benchmark amongst themselves. That has played a critical role in the success. If Mototolo introduce a new technology and is successful, then it is easy for all the other mines to go and benchmark and also try to achieve the same results.” **RPT6**

There are lessons to be learnt in the Eastern Limb. While the mines south of the Steelpoort fault are owned and operated by six different mining houses, the culture of learning, sharing and growing together is evident, and best practice is not just another buzz word. They live it.

Sharing knowledge

As described above, this has been the driver of benchmarking. Organised forums have been the vehicle for benchmarking and sharing and transfer of knowledge among the managers of different mines and mining houses.

“That’s why we, together with the Mine Health and Safety Council and the DMR (Department of Mineral Resources) we are working towards best practices that we can learn from all our sisters or our mines, our colleagues to see how best we can bring that number of FOG related accidents and TMM related accidents. So yes, I agree with you on that.” **RPT3**

“Whenever there is a new technology that my colleagues are actually trialling and testing ... we go all out with other colleagues to go and learn so we can grow as a district. So we learn from each other.” **RPT3**

“And obviously the other thing is, because in the Eastern Bushveld Complex, sharing of knowledge amongst management also plays a critical role in the forums like AMMSA (Association of Mine Managers of South Africa), AMRE (Association of Resident Engineers). There is a sharing of this knowledge and the success that happens. That also assists.” **RPT6**

Internal skills development

Mines in the Eastern Limb are passionate about their people. Their success with operators is built on careful selection, mentoring and nurturing. They recruit young school leavers from the communities, teach and train them, model their behaviours and provide them with the necessary skills to be effective when performing their tasks.

"I am going to segment the two. I want to start first on the Eastern Limb. The success of the Eastern Limb is that we are taking matriculants directly from school on to the mines. They do not have prior experience of the mine. So if we teach them the behaviours that are expected on a trackless technologically advanced mine, we get the benefit. So, I have unpacked the operators. The operators have no other behaviours, you actually teach them your trackless behaviours." **RPT7**

"I still want to talk about the Eastern Limb. I visited one of the mines here in the valley to a manager who worked his way up from being an operator. The way he ran his section was so seamless. I asked him. When machines are not available would you do something different? He said, I don't know any other method. So it is very, very important to have educated guys and guys that just know only trackless." **RPT7**

"I don't think that employers have necessarily applied themselves adequately around screening, training and developing people to take on new technology. Our new mining technology group where they have taken people from other areas and have done the attributes screening around many factors have been successful. But they have taken the time and effort, because they do not want the approach to fail. And in the process, they have rejected a large number of people. So the rejection rate for employment rates in the new mining technology area and it's not based on anything like people would normally say, race, gender, language, schooling. It's not. It's invariably around the ability to adopt and work in a spatial context remotely, so how you do work. Screening has been very challenging because you have had a discard rate or rejection rate. I am speaking like a metallurgist here, discard rate, rejection rate of people of sometimes 9:1 before we have recruited. We need to get people with the right attributes. So, I think, selection of people to work on new technology or the lack of selection has led to the demise of modernisation." **RTP21**

The success of mechanised mining in the Eastern Limb is built on its people. Their employees do not know any other way of working other than what they have been trained on by their employers. Compared to employees observed at a mine in the Western Limb, the operators there were described as militant and illiterate. The culture of coming to work every day and looking after equipment was non-existent.

Having an educated workforce working with expensive equipment has been the reason for the success of mechanised mining in Zimbabwe's Mimosa, Unki and Zimplats mines. This observation is made from best practice visits made to these operations. Having simulators in the training centre was an advantage in the mines which had them.

Access to Education

Education is an integral part in running a mechanised operation. This facilitates usage of a common language at the workplace, and enhances training effectiveness, understanding of equipment operating manuals and check lists. The Eastern Limb operations and Bathopele mine have been successful in applying this simple standard.

"Taking for instance the likes of Bathopele. The people they employed at Bathopele had to have a certain level of education or minimal level. I think you needed minimum standard 10 or grade 12. That was required. This contributed to the success of the technology at Bathopele." **RPT16**

"The historical labour pool is so sodden. It's where people have historically been disadvantaged and they do not have the necessary level of education. In other words, they are illiterate and you cannot run a trackless operation with illiterate people. So, over a period of time, these operations have eventually gone to a point where they have looked at people and in some cases only matriculants." RPT1

Adapting to new systems

The transition from conventional to mechanised operations has not been easy. The difficulty has not only been with the sourcing of correct equipment, but also finding the necessary skills to operate and maintain the expensive equipment. Recruiting an illiterate workforce from the often impoverished labour sending areas, and from conventional gold mines without enough bridging, has made the adoption of new systems painful.

"It's not the people that are employed. There is nothing wrong with the people. Whether we take in somebody employed in the platinum mines or we take in somebody from the gold mines. It's got nothing to do with the people. It's got to do with the training that they have received and it's got to do with the culture which is being created around how they operate when people move from another mining industry into the platinum industry." RPT21

There is no doubt that people make a difference. The newer mines, which have demanded a certain level of education and comprehension among their recruits, have benefitted.

It all starts with the selection and recruitment of operators, service personnel, supervisors and managers. This is followed by training and nurturing. Dover/Vienna testing, coupled with the use of simulators, has gone a long way in instilling a new method of working.

Mines have further resorted to recruiting training instructors from Australia to up-skill their operators, service personnel, supervisors and line managers.

Mines in the Eastern limb have expressed satisfaction with the results of this initiative.

Young employees' impact

Young employees who have interacted with technology from an early age learn fast and adapt easily to what the mechanised operations are trying to achieve. According to the participants, the younger the work force, the more successful the company is likely to be.

> "I think here I am going to use a straight forward example. If you compare this mine to any of the Kroondal mines then you will have a look, the average age here is much lower than the rest, we are far more advanced than the rest on mechanisation. So I think to be successful, you will have to target the correct workforce. But if I take one of these youngsters, and take him to go and do a licence, it's like this, they pick it up. It's just this whole technology thing, they have grown up in a different, whole different time warp, so they are...so the more mechanised you want to go, I think the younger your workforce will be and be successful." **RPT12**
>
> "The platinum industry has got to employ a new generation of miners. The potential of innovative ways of mining can easily be adopted in an environment like that. The young generation is there and promotes acceptance of new technology and make it successful." **RPT16**

The younger generation knows only what we have taught them. They are the future. They must be nurtured. Mechanisation is providing this industry an opportunity to fix the excesses and mistakes of the past.

5.11 Theme 5: Gender transformation

Gender transformation remains a critical imperative within South Africa. The country is still striving to improve the imbalances of the past. Women were not given same opportunities as the men, and this was particularly true within the mining environment. In South Africa, it was illegal to employ women underground.

> "If you think of mining in the 1960s, you know...male dominated and you will get employed based on your physical strength and how you look. Mining was no place for females." **RTP11**

Changes have been made so as to improve the number of women employed in the mining industry. This is taking place, in an environment where society still has a mentality that women do not belong in the mining space.

> "We are living in a country where we in any case still have a belief of women as inferior to men. We still have a belief in the country where women are supposed to look after kids and men should be at work." **RTP5**
>
> "So in a very strong misogynistic society or society which is intolerant of women in the workplace and women taking roles which are traditionally male, the technology won't solve the problem because the social pressure will be greater than the benefits provided by the technology. So, the social context I think is a bigger driver than simply the technology rather than anything else." **RPT21**

Despite this there is a gender transformational agenda which demands that women are treated and given the same job opportunities within the mining industry, with 50:50% chances between men and women.

“Conventional mining in its current form with what’s left will not work for transformation maybe as the National Development Plan would like it to be. Never mind the Mining Charter. The transformation agenda is 50/50. Not 10%, especially looking at the new mining charter.” RTP5

Generally, all the participants agreed that mechanisation in mining has contributed to gender transformation (Figure 5.5).

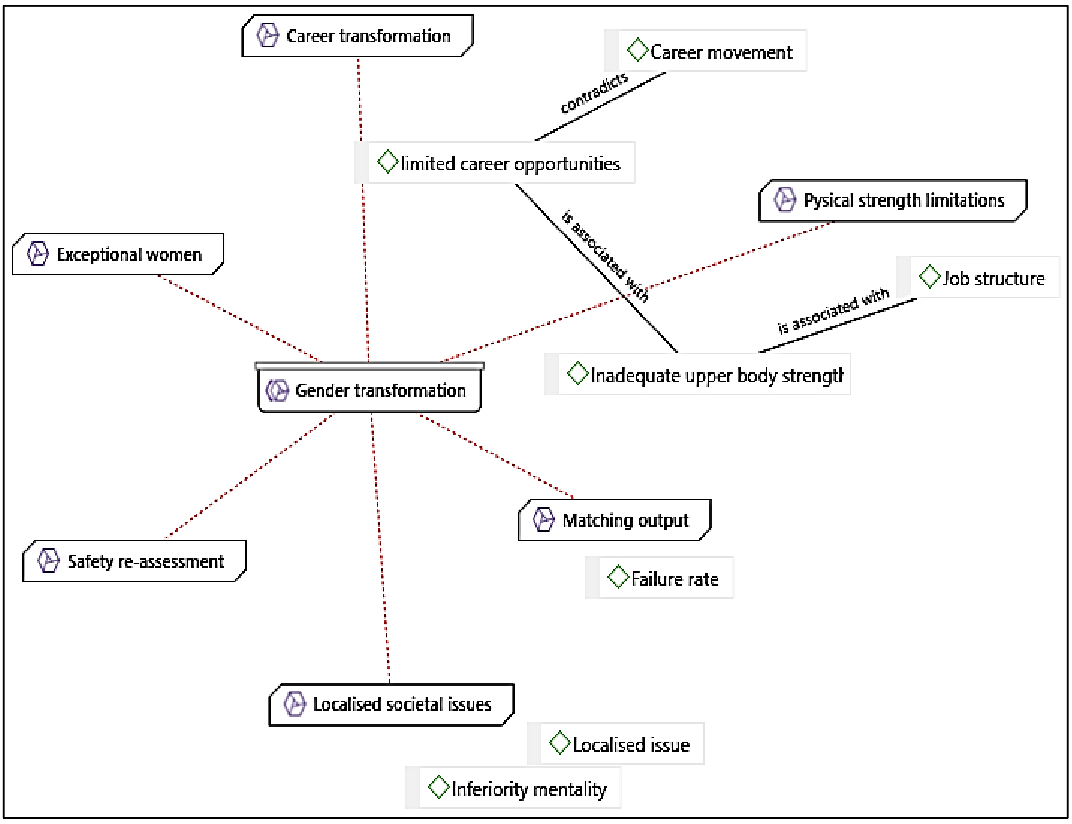


Figure 5.5 Gender transformation

There are now equal opportunities for women in mechanised mines. This has facilitated career progression for women. It has enabled them to perform at much the same rate and mastery as men and sometimes even better.

"On a trackless mine, it does not make a difference what gender you are. If I take some of my best shift supervisors, some them are women, some of them are men. Miners the same, operators the same." RTP12

"It's either you accept that female workers should be able to deliver as much as men can deliver. And on the same breath, one will say, mining underground, underground environment is a physical labour environment, which a lady or a woman will not be able to fit in. So how do I now help? That person who is now not as strong as a guy, as a man but at the same time I want to accommodate that person in the work space? Technology can then play a vital role then in assisting particularly females." RTP16

"If you look at Two Rivers being a mechanised mine, I have no hesitation in employing women as operators as compared to conventional mines where you had to think rather twice about finding a woman." RTP8

Women are citizens. They have a right to gainful employment.

Limited physical strength

Traditionally, women have lower physical strength than men, and this was a limitation in job structure and career opportunities. This barrier has been eliminated by mechanisation.

"Technology instead of like the conventional mines whereby let's say for a driller you had to have the physical capability. It's totally different because you can operate a huge machine on a joy stick." RTP7

"You are not having the strength, the physical strength of the people any more. So, mining, traditionally is physical work. So by implementing technology and mechanisation, takes away that physical work because now a machine can assist." RTP13

"First of all, let us look at the gender part of it. First of all, if you look at gender and you look at technology on Bathopele for example, there will be limited opportunities for women." RTP14

"Mining haul trucks when they first hit the market, did not have power steering. You never saw a single woman driver of a mining haul truck on surface operations. You can do a check across the Australian and American mining industry and watch. You can do a correlation of female employment versus adoption of power steering. The two are directly correlated. Introduction of power steering opened the way for women to become haul truck drivers. As you have travelled to Australia, you go to Australian mines, 90% of the haul truck drivers are women. So, the ability to take physical strength out of doing the work will allow gender transformation. But more importantly, there has got to be an enabling social environment which allows women to be in the workplace." RPT21

Participant 17, provides an estimated number of failure rates for women compared with men in conventional mining operations. The participant put the Functional Work Capacity failure rate at 60%. Technology has transformed this situation.

"Yes, failure rate for females is at least 60% more than males. RTP17

As with the power steering innovation, the industry needs to continue developing ways and designs that will enable females to actively participate in the economy.

Exceptional women

Women have physical limitations. The participants acknowledged that there are exceptions to the rule. There are women that are as strong as men, but as they are few and far between it does not assist in creating a fully transformed environment. We must continue to develop technology that enables females to be productively employed. This will create the required workplace gender parity.

> "There is this mentality that women cannot be on the LHD. There is nothing legal that is stopping them. I think there is one lady that I know that is on the LHD. That is the first one." RTP14
>
> "Never mind being a woman, there are males that will not be able to drill. Conventional mining is physical work. There are very few women that can endure certain occupations." RTP5

The ergonomic requirements of the LHD need to be such that it can comfortably be operated by female employees. Because the LHD is currently hot and bumpy, women are staying away from it.

Matching outputs

With technology, women have the same performance opportunities as males. Some are outperforming the males in term of the production output.

> "I agree with that one. Women can now also drive LHD and operate machines." RTP2
>
> "I have seen technology and mechanisation actually assisting. We have females taking over the roles of LHD and Rig operators." RTP3
>
> "The norm is about 40 bolts. You are quite good if you can do that. It's 40 bolts, it's 3...3...3 bolts that we can support, now this one can do 60. Why? It's because she is able to play with the joystick. It's not physical capabilities, it's now how quickly can you react. How are your reflexes when you are working with the machines?" RTP7

Career transformation

Overall, technology is transforming the mining industry and is assisting in overcoming gender inequality. As long as there is goodwill and willingness by management to attain gender equity in the workplace, it will be achieved.

Safety re-assessment support

To ensure a smooth transformation, there are initiatives for women in mining to ensure continuous re-assessment of safety and health issues. Transformation can never be to the detriment of the women's well-being.

> "Chairman [chairperson] of Women in Mining for this mine attends all safety meetings. She assists with PPE issues and other safety interventions." **RTP4**

At the end of the day, the safety issues associated with conventional work are not ideal, even for men.

In summary, it is clear that the core mining work is labour intensive and physical. Will mechanisation be able to positively contribute towards gender transformation? The application of mechanisation decreases the physical exertion requirement and allows women to be as productive as their male counterparts. The labour pool is increased by including the entire adult population of the nation, male and female. Mechanisation has contributed and will continue to play a role in the transformation of this industry.

5.12 Theme 6: Health and diseases prevalence

Injury and disease prevalence is a current reality that is found within the mining industry.

HIV realities

In the past decade HIV/ AIDS have been the diseases that has attracted most attention, including their influence on the performance and productivity within the mines. Currently, there is a mixed reality of HIV/AIDS in both workplace and communities. There are sections, especially of the workplace, which propagate and treat HIV as similar to any other disease. Some of the participants mentioned that nowadays it was treated like flu.

"Mining industry has been HIV affected. Most of our mining towns or most of our workforce is highly affected by HIV." **RPT16**

"As long as your mind is there you have a positive mind set towards conducting your daily duties and you follow your doctor's orders in terms of taking your medication, you have food to eat and activities to do, it shouldn't be a problem. The active life that you live even for an HIV suffering employee shouldn't be a problem for them to continue working in an environment where there is mechanisation." **RPT3**

"You must take your one tablet every day, you can't skip and you can live a normal life." **RPT12**

Despite this, there are still some elements of stigmatisation, especially in the communities where the society is intolerant.

"And then the issue of social acceptability comes in to say, are we a society that is currently able to incorporate without bias people who are known to have HIV or other diseases or other social attributes. I think of the incredible bias we have against foreigners, the xenophobia coupled with what do they call it, Lesbian, Gay, Bi Transsexual I can't remember what the I is. LGBTI groupings.

We are an incredibly intolerant society. So in that social circle it's not only a disease." RPT21

HIV/ AIDS is not the death sentence it used to be. Affected employees need to take their medication and live healthy lives. There was a consistent message across the participants, that within the workplace, the HIV status was irrelevant, and it was not influencing the work or the career of the affected employees (Figure 5.6).

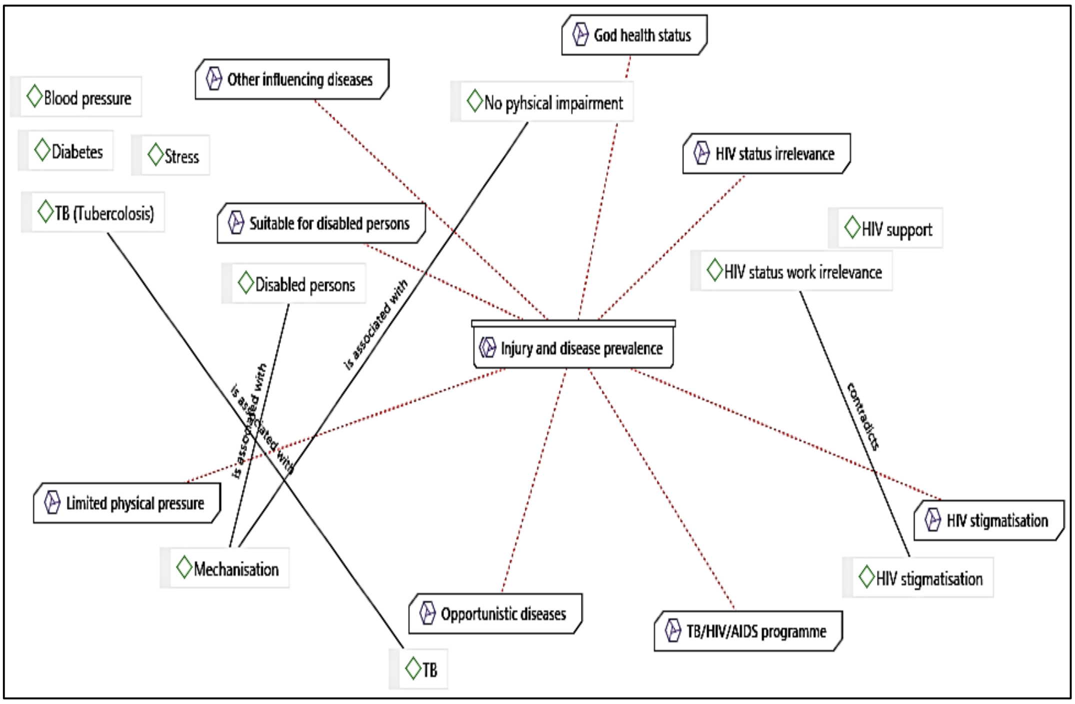


Figure 5.6 Injury and disease prevalence

Opportunistic diseases

Despite this, participants acknowledged HIV, like most diseases, sometimes compromises the immune system. Mechanisation does positively contribute toward quality of work life and limit the physical pressure on the workers.

> “Well most people die because of tuberculosis, that’s a worldwide phenomenon. Whether it is associated with HIV or not that’s a different story.” **RPT5**

Other influencing diseases

This is not only applied to HIV aids, it is also applies to other diseases which are increasing, and influencing productivity, such as stress, diabetes and high blood pressure.

> “It’s just like any other disease. We can go underground now. We will walk past a lot of people, but you will not know if that person is HIV positive, whether that person has got high blood pressure, you won’t know.” **RPT12**
>
> “What we see now as the biggest challenge and I spoke to the medical practitioners where I work now. They said listen, our biggest problem now is high blood pressure, diabetes, and stress related issues. Those are the things that now are a bit of a challenge.” **RPT11**

There is a general acceptance that HIV /AIDS is there in the workplace. Attitudes towards such people have changed for the better.

Limited physical pressures

Overall, mechanisation allows for the ease of work, irrespective of the diseases. Mechanisation assists those with compromised immune systems. It allows for people with disabilities to be employed and to work within the mining industry in the core mining operation, without compromising on productivity, quality, health or safety.

"If you go and work in an environment that is excessively hot and there is physical work, we can say what we want, it's a filthy environment. That is why we have the rates of tuberculosis we have. It doesn't matter what we do with silicosis and pneumoconiosis and all those things, it will just get aggravated if you have an immune deficiency." **RPT5**

"I honestly think that technology and mechanisation will definitely facilitate the achievement of workplace gender transformation and it will accommodate those and not only employees suffering from HIV but also those that are either injured in the workplace and to a certain extent people with disabilities." **RPT8**

Productivity drops

This is critical. A poor state of health is known to result in a huge productivity drop, so mechanisation has been found to be useful.

"If people are affected with HIV and they are not productive. Obviously that becomes a bit of a problem. As it is now, the productivity of most mining houses is declining. This decline requires that your workforce needs to be healthy." **RPT16**

Technology and mechanisation have assisted reversing the downward spiral of productivity caused by an ever increasingly sick workforce. Mechanisation, together with the provisioning of medication and education for employees on the benefits of a healthy lifestyle, have ensured the industry will survive well into the future.

5.13 Theme 7: Injury and occupational diseases prevalence

Injury and occupational diseases are generally inherent within a mining operation. It was interesting to discover whether there were differences evident between conventional mining operations, and those using technology in their operations.

The description below candidly described what conventional miners are subjected to in terms of the environment and working conditions.

> "Conventional operations are arduous, uncomfortable, and not ergonomically appropriate. Every possible thing that you can think of, if you had to devise and put on the table a mining method now for approval by a group of people to say this is how we are going to do it. We are going to take a person, we are going to take a person and put them into a stoping width which is a lot less than their height, perhaps half of their height. They are going to work in a cramped space, operating a piece of hand held piece of equipment which has a particular vibration frequency, which induces white finger disease, noise levels which create occupational deafness, produce a fog which has got oil in it. Produces dust which may or may not have silica content depending on which mine you are on. T**he point is, no one would approve it.** No board, no technical committee would approve it. So, it's a legacy issue. So I don't think it's even a debate. Mechanised has its own challenges in terms of different frequencies especially on the drill rod impact, piston impact on drill rods, bit…by the way we are moving to less impact drilling to cutting." **RPT21**
>
> *(Author: The bold text is my own emphasis.)*

Environmental conditions

In most cases, stoping workers in conventional operations spend their shift on their knees. Oils are spayed in the general atmosphere where employees are working. They ingest these oil sprays. Generally, it is a dirty working environment which is, more often than not, noisy, hot, and with inadequate lighting.

What became evident in discussion with the participants, was both injury and occupational diseases were highly influenced by the conditions in which the operations were taking place. Figure 5.7 presents the dominant conditions which are present and the differences between conventional and mechanised mining.

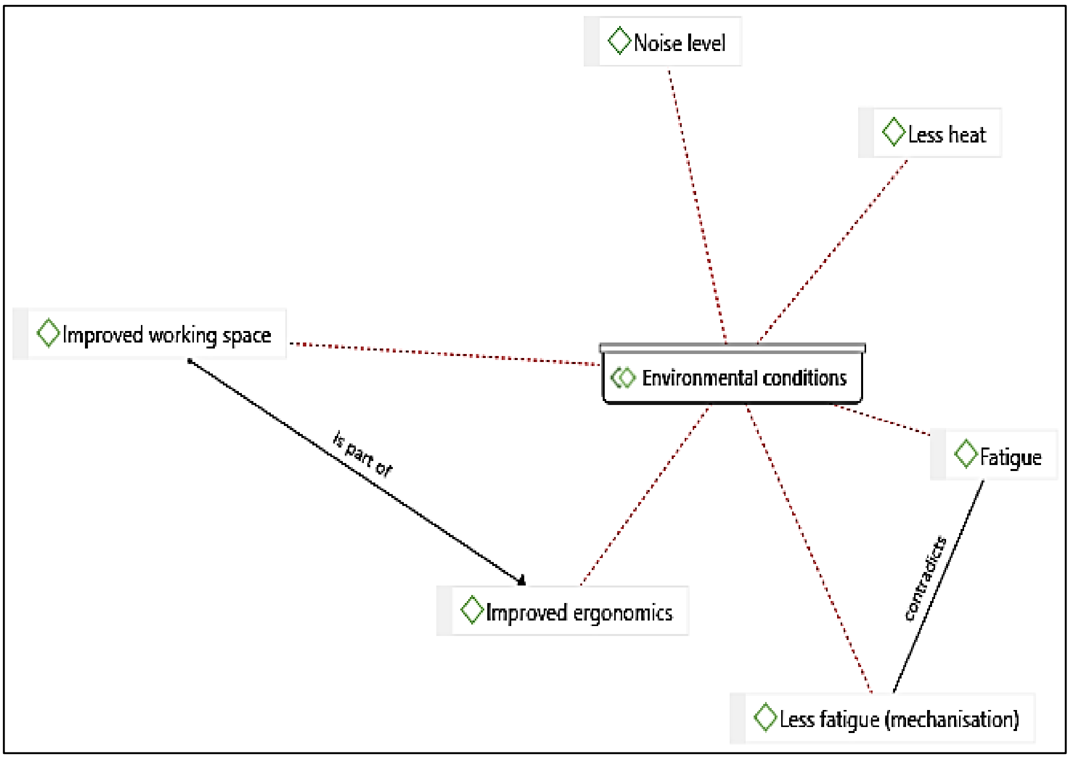


Figure 5.7 Environmental Conditions

The participants felt there were major differences in ergonomics, noise levels, heat, working space and fatigue between these two mining methods. Generally, they agreed there were less heat related disorders in the mechanised mining environment.

"It's relatively shallow compared to most of the conventional mines, which means it's a lot less heat. So, for me, the mining method in essence is inherently safer than the conventional way of doing things."[RPT5]

"You got the machines where the noise level is reduced to a certain level... so the risk of having people losing hearing has already been dealt with." **RTP6**

Furthermore, the majority of the participants were of the view that the noise level decreased with the mechanisation method.

"Your noise from your hydraulic drill is just as high as the jack hammer but there are not so many of them." **RTP1**

"On most of these machines, the noise levels are within that same range. The LHDs are the ones that give you more noise. So if these guys are not driving the LHDs you will have less of noise induced hearing loss." **RTP 9**

Although this was the view, there was a participant (RTP2) who believed it was other way around, that mechanised machines generated more noise than the jack hammers.

"Your noise levels on your machines are pretty high (high pitch) and the guy on the drill rig must protect their ears and can use ear muffs as they are not exposed to the water, the oils and the dirt." **RTP2**

Similar disagreement was also found with fatigue. Respondent 2 indicated there were still higher levels of fatigue with the mechanised processes. Again, despite this, the majority believed there was less fatigue for the employees with the migration from conventional to mechanised methods.

"You get fatigue by hard labour. There is a different type of fatigue that comes with just sit and ride. In opencast, they now have these things that they build in that if it detects something in your eyes, the car slows down because it senses and detects fatigue in your eyes." **RPT2**

"You're not exhausted like on a gold mine when you walk into one of those extremely hot places. It's confined, you have to crawl from one stope to the next, from one gulley to the next. With mechanised, you don't exert as much energy." **RPT4**

There was consensus that there were considerable workplace ergonomic improvements when the mine is using mechanised methods. Among the ergonomic improvements was the working space, which was considerably bigger.

"On the gold mines the spaces that we work in are a lot more confined. I can tell you now, here we have 8m boards and it's 2.1m wide. You walk, you don't have to crawl in the mine. You don't get as hot." **RPT4**

"Ergonomically you are not challenged. It's a lot better environmentally in terms of ventilation systems and so forth and dust and all those kinds of things." **RPT5**

While people may have different views, the working condition in mechanised operations are superior. There is enough space for people to travel in natural positions. Ventilation air control is easier and manageable. Travel is by vehicles, so is lifting and transporting.

Prevalence of occupational diseases

There are prevalent occupational diseases in the mines. Some have developed due to the environmental conditions of the mines. From the discussion with the participants, it was evident that in addition to the developed ones, there were employees who might have pre-existing conditions. One of those conditions is phthisis. Within the platinum ore, the silica is insignificant, unlike in gold industry. As such, if an employee is diagnosed with that occupational diseases the likelihood is it was a pre-existing condition.

While platinum dust might be silica free, is not supposed to be ingested by the employee. It has a nuisance factor.

> "Phthisis, here we don't have silica dust. So, we shouldn't have a case of phthisis here because we don't get silica dust. We don't get silica in the UG2 orebody." **RTP4**

Participants stated that six main occupational diseases are prevalent in mines. Associated with conventional methods of mining, these were given as lung conditions often associated with dust exposure and manifest themselves as:

- Tuberculosis
- Phthisis
- Pneumoconiosis.

Associated with mechanised mining methods were:

- Lung cancer
- Noise induced hearing loss
- Musculoskeletal disorder
- Female reproductive system disorders

- Kidney disorder

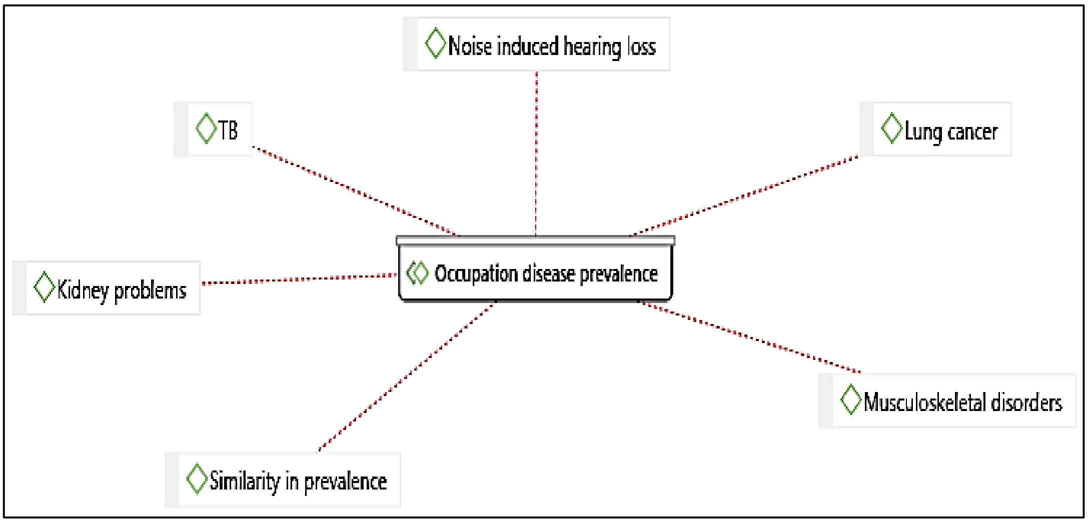


Figure 5.8 Occupational disease prevalence

As already indicated, phthisis is not prevalent within the platinum mines, but more on gold mines. Diseases associated with conventional mining methods are a result of the environmental working conditions and work designs. Diseases associated with mechanised mining methods result from inadequate engineering of plant and machinery.

> "That's basically about it. The noise exposure, the musculoskeletal diseases, pneumoconiosis due to dust exposure. Musculoskeletal diseases are due to inadequate machine ergonomics." RTP17
>
> "Diesel machines brings diesel particulate matter. When we started with mechanisation, we were not aware of what that oil stuff does to your lungs. It's a straight out killer. It's carcinogenic." RPT2

Although, noise induced hearing loss was one the main occupational diseases highlighted by the participants, there was some level of disagreement. The majority believed it was a result of conventional methods, with the LHD being the main culprit with mechanised methods.

> "If you are talking health, Noise Induced Hearing Loss and stuff like that especially with face workers, it is much higher with conventional. We did not measure these things over the years. We only started measuring them in the last couple of decades. But they will be much higher. There are many conventional employees with noise induced hearing loss. The reason is simply the time of exposure to the noise at the face. The mechanised drillers wear proper ear muffs and can operate from a cabin." [RPT1]

Overall, there were mixed views on the prevalence of occupational diseases from the two mining methods. Some participants suspected conventional methods were worse; based purely on the improved absenteeism rates after mechanisation.

> "To tell you the honest truth, I haven't seen a lot of difference, but I will tell you where I have seen the difference. Occupational disease affects your attendance whereby most of the time your people are not at work having to report to the medical station. Now, in the trackless mines, you do not have a lot." [RPT7]

The work environment in a mechanised operation is more controlled and orderly than in a conventional one. Environmental conditions are, therefore, much easier to manage. This is a big positive in enhancing the quality of workplace conditions, as well as the health and safety of employees.

Injury rates

There was an overall agreement that injury rates were worse in conventional mining methods. Mechanised methods have lower injuries, better safety records and improved attendance. Fewer mechanised employees go to the medical stations (Figure 5.9)

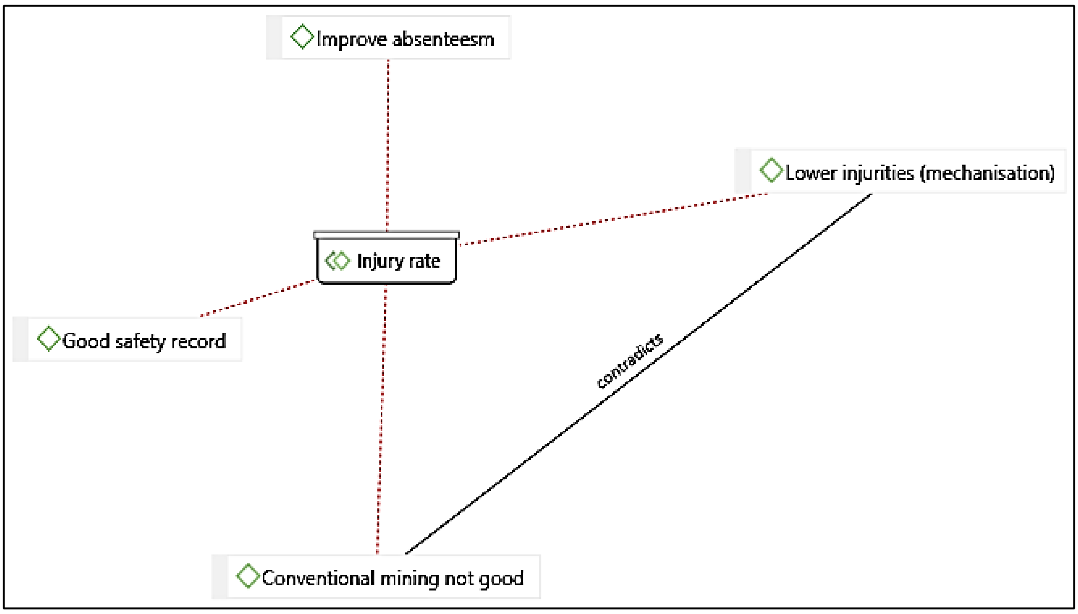


Figure 5.9 Injury Rates

The good safety records due to mechanisation was evident from the statistics being monitored by the mines.

> "Our safety rates currently sit at 0.3 per 200 000 man hours for the financial year. This is the lost time injury rate. There is not one conventional mine worldwide that can compete with these numbers." **RPT5**

Respondent 7 articulated the improvement in injury rates with mechanised mining methods best:

“Recently, and when I am saying recently, about two weeks back, our CEO was presenting the results to the markets. You can see the injury rate, the total injury rates of a trackless mine and a conventional mine...it’s day and night. It’s minute, our injury rate is a fraction of what a conventional mine is.” **RPT7**

In summary, discounting the pre-existing conditions, the environmental conditions contribute towards the prevalence of occupational diseases and injury rates with no particular mining method contributing effectively to minimising or eradicating them. Despite that, mechanised methods were found to be much safer than conventional ones, in terms of injury rates.

5.14 Emerging insight

Current thinking is that the technology we are developing and deploying into South Africa’s UG2 in the Bushveld will work and provide benefit for a finite duration. Emerging insights are dictating the need for research and development which moves away from the current technology of drill and blast to a continuous non-explosive means of production, and which removes people from the primary rock breaking activities.

“I don’t think it’s [current mechanised mining methods] enough to carry us for another 50 years. I don’t think it’s enough in fact to carry us for 20 years. I think it has a window of about 5 to 10 years before it gets superseded by other approaches. So it’s an incremental step. It’s still drilling and blasting, it’s sequential mining, it’s mechanised mining, it’s difficult to automate it. So, it will be superseded by stuff which is continuous mining which is readily automated.” **RTP21**

“...We simplify it down to a scale driven by geologist’s hole spacing and interpretation and come up with this thing called a narrow tabular orebody. It actually is not a narrow tabular orebody. It is a narrow squeezed piece of undulating ribbon that goes through the rock. If you look at the cutting stopes that have been successful in the industry and I would like to think we got the most of them and you go in there, what I had from drill and blast experience had looked and said, what an incredible hanging wall. It's smooth and planner, beautifully supported.

Look at this footwall, you can drive my Audi over it without any problems. When you go into that same piece of orebody that's now been cut, you realise we were fooling ourselves by blasting and breaking to planes of weakness, rather than the contour of the mineralisation. The contour of the mineralisation actually waves continuously and that top contact in some places has got an amplitude of 150 to 200mm over a wave length of a metre. So it is moving like this the whole time. We fooled ourselves into thinking that it is planar.

The future of mining outside the next 5 to 10 years I think beyond the 10 year space, is equipment that is actual sensing and moving with the hanging wall or footwall contact. Just like the oil industry, when they put down for fracking or for oil extraction holes they drill holes of... they start out at 900mm diameter end up at 150mm.They are guided and steered on a less than meter by metre basis by on board sensors that are detecting changes of where they are in the equivalent of our mineralisation. So there is no reason why, I am just trying to think…a gamma ray detector will tell the difference between UG2 and country rock and you will be able to steer it on a contact all the way. So will the equipment be able to handle …let's call it strike and dip undulations is where we will have to go." **RTP21**

"I think one needs to distinguish ideas and doable ideas. Ideas of propeller heads. Who did I speak to the other day and they said they are seeing people from NASA. For those robotics." **RTP2.**

"I think mechanisation has limited scope because of the tabular ore bodies that we have. In its current form, Mechanised Technology, I think there is limited scope currently. I think it links to Porter's paper that says we have to look at work systems and through modernisation it will lead over time to some mechanisation taking place." **RTP 5**

In summary, while there have been spectacular failures in the application of technology and mechanisation, the participants felt that, overall, the application of technology and mechanisation has modernised and benefitted the industry. Benefits which are visible, measurable and quantifiable in terms of:

- Output
- Health
- Safety
- Gender transformation
- Overall business profitability

While tremendous progress has been made, thought leaders within the participants see a finite life in the current initiatives. They see a need to move away from current technology relying on the cyclic drill and blast methodology, to a continuous rapid excavation method which reduces, if not eliminates employees from the rock face.

6 DISCUSSION OF THE RESULTS

6.1 Introduction

In chapter five the findings of the study, based on the empirical data analysed using thematic analysis, were presented. This resulted in 194 initial codes which ultimately resulted in seven themes:

- Technology critical success factors
- Mechanisation and innovation
- Employee role on mechanisation
- Gender transformation
- Health and disease prevalence
- Injury and occupational disease prevalence.

In this chapter, the findings are discussed. But, before this can take place, an evaluation of the credibility of the study is put forward. In the next chapter, a conceptual model for developing an application of Mechanised Technology in South Africa’s Bushveld UG2 narrow tabular orebody is presented. Conclusions, limitation and recommndations of the study are also made.

6.2 Credibility of the study

The credibility of the study is highly dependent on the design, data collection and the data analysis employed during the research. In this study, the design was selected as the qualitative method which used an interpretivism paradigm. This was appropriate, as the aim sought to understand the application of Mechanised Technology.

Interpretivism allows for the participants to share their world reality and experience pertaining to the topic of interest. This was congruent with the explanation by Crotty (1998) who said that in interpretivism, the selected participants are generally highly knowledgeable to provide insight for the research. It is important the researcher recognises the world does not exist independently from the people’s knowledge of it, with the people being the primary source of the information.

In this study, the people interviewed had in-depth knowledge of narrow tabular UG2 mining within South Africa's Bushveld environment. There was a huge amount of experience between them. This included:

- General Managers both current and retired
- Industry Consultants
- Human Resources Practitioners
- Occupation Health Practitioners
- Operations people
- An Entrepreneur (see Table 5.2 in chapter 5).

The relevance of the selected sample is supported by Guetterman (2015), who argued that sample relevance and sample sufficiency are key to credibility of the study.

In addition to the design, was data collection. In this study, the critical aspects were:

- The focus of the interview guide
- The sufficiency of the data collected.

Interview guides were used to eliminate observation error and also ensure that questions were asked in the same, consistent manner. This was done to improve the dependability, consistency and reliability of the study.

The guide used is presented in Appendix 5, and the systemic approach of alignment of the interview guide questions to the research objective was discussed in chapter 4.
As to the sufficiency of the data, which was about the conformability (Lincoln & Guba (1985), in Morse et al. (2002)), the sufficiency of the interviews was evaluated with two methods.

Method 1: The number of interviews were found to be within the optimum range for phenomenology studies which ranges from 5 – 25 (Saunders, et al., 2015). There was a total of 20 in this study. This is supported by the sample size analysis study by Morse (2010) who found that 15 to 20 was the optimum number of the interviews for a phenomenology study.

Method 2: this study reached data saturation after 18 interviews. The saturation graph is presented in Figure 6.1

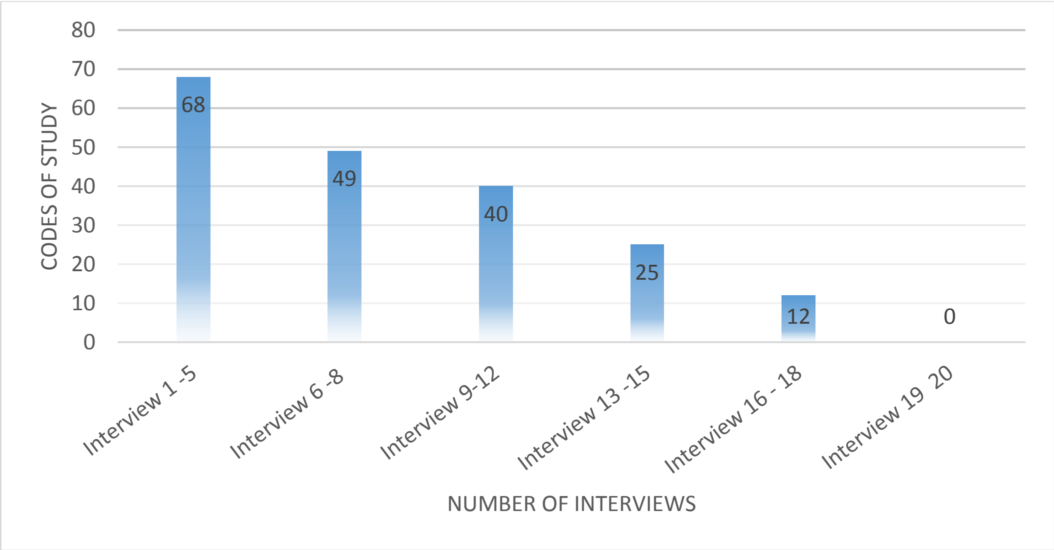


Figure 6.1 Data saturation graph

The credibility of the findings was also ensured during the data analysis.

- The data was transcribed verbatim to ensure the findings reflected the true views of all the participants, without any adjustment to the original data. This was done to strengthen the credibility and internal validity as posited by Qu & Dumay (2011).
- Three interviews were randomly selected and sent to the participants to confirm the content and context. This ensured the reported data was accurate. (Appendix 12)
- During reporting, contrasting views were also reported to ensure objectivity of the reporting.

Based on the above, therefore, it can be confirmed that the findings of the study were regarded as credible.

6.3 Application of Mechanised Technology in to South Africa’s Bushveld UG2 narrow tabular orebody

Objective #1:

Reiterate the need for the application of Mechanised Technology into South Africa’s Bushveld UG2 narrow tabular orebody.

The first objective of the study was to understand the need for application of Mechanised Technology in to South Africa’s Bushveld UG2 narrow tabular orebody. There were four main findings supporting the need for application of Mechanised Technology, these were:

- **Improved Productivity**
- **Decrease of Injury Rate**
- **Support of Gender Transformation**.
- **Decrease of Occupational Disease**

There were mixed views about the decrease of occupational diseases. If leveraged, the decrease in occupational disease can add to the compelling need to apply Mechanised Technology.

Improved Productivity.
It was evident from the findings that mechanisation was associated with an increase in productivity, compared to conventional mining. This was mainly due to a lower workforce input for a similar or better output. This was congruent with the findings of Gustaffson (2011) and supported by Lynch & Hamilton (2012) who argued labour reduction and flat organisational structures are benefits of mechanisation and automation.

The findings also indicate there is higher output in less time and improved output, even for employees who are sickly. This is because there is less effort exerted for same output. Hatting, et al. (2010) assert that technology and mechanisation accommodates workers suffering from HIV/AIDS. In the study, participants stated that employees with compromised immune systems

benefitted from mechanisation and technology application.
Females who generally have lower output than males in conventional mining are now matching their male counter parts.

This improvement in productivity is critical in South Africa mining as this sector remains important in the country's development. Economic growth can only be achieved by increasing productivity (Fisher & Schnittger, 2012). The improvement augers well for the challenges in South Africa which have been identified as one of the countries with declining productivity (Ernst &Young, 2014).

South Africa's mixed results on deploying machines in the narrow tabular orebody environment of the Bushveld Complex, has resulted in automation not taking place. This has caused opportunities to improve the much needed productivity improvement in an industry faced with declining revenue due to inflationary pressures and fluctuating PGMs metal prices to be missed.

Decrease in Injury Rate.
Overall, the findings show there was a significant difference in the injury rate between the conventional mines and mechanised trackless mines. Conventional mines have a higher number of injuries. This is in line with the literature which affirms there is normally a low level of injuries in mechanised mining.

Webber, et al. (2010:278) shared their Lonmin experiences, "…health and safety within the mechanised operations has performed relatively well when compared to the conventional areas. No fatal accidents have been recorded in the last four years on the mechanised shafts. The LTIFR (lost time injury free rate) rates have outperformed conventional areas. Hossy XLP site has achieved a year to date LTIFR of 2.31. No LTIs have been recorded in the the stoping or development environment for the year to date. Maximum noise exposure levels have been reduced to below 100 dB in mechanised areas with no new NIHL cases been recorded since 2008."

Rhodes (2015:37) agreed. His observation was, "…with such a reduction in stope labour there was justification in claiming that in mechanised operations, with the lower complement of workers exposed to the conditions, there could be less accidents from falls of ground. Also, with mobile equipment designed to operate in higher workings the persons injured from falling from fixed ladders and drilling platforms could be eliminated."

Egerton (2004) concurs. According to him, health and safety are improved because fewer persons are exposed to hazards, and because the machinery, equipment and systems utilised are intrinsically safer and conditions of the working environment are generally better.

Note that while injuries in mechanised operations are fewer as stated in Webber et al. (2010), when they do occur, they are normally very severe.

Gender transformation.

The findings show that mechanisation was supporting gender transformations. It has enabled women to work in jobs that they would not have ordinarily worked on in the conventional mines. Mechanisation has enabled them to match their male counterpart on productivity.

It is true that in conventional mines, environmental conditions are hard and physical exertion is required. Farren (2002). It makes it difficult for women to operate effectively and safely in such an environment.

Hatting, et al. (2010) assert that technology and mechanisation facilitates the achievement of workplace gender transformation. Other studies also agree with the impact of technology and mechanisation on the productivity of women, when compared to conventional, hybrid and other mining method variations as stated in Musingwini & Minnitt (2008).

Decrease of Occupational Disease.

The findings in the study showed the use of technology was associated with a decrease in lung related diseases and in noise induced hearing loss.

The findings of the study were in agreement with the literature of Webber, et al. (2010.) They observed that health and safety within the mechanised operations has performed relatively well when compared to the conventional areas. This is one of the main motivators for mechanisation, in view of relatively risky and dangerous operating conditions in underground mines.

Despite these positives, it is clear there are machine design issues which are creating unintended health and safety risks. OEMs need to improve these design flaws.

According to Lloyd & Cackette (2011), the diesel engine is the most efficient prime mover commonly available today. But diesel is one of the largest contributors to environmental pollution problems worldwide. Diesel emissions contribute to the development of:

- Cancer
- Cardiovascular and respiratory health effects
- Pollution of air, water, and soil
- Reductions in visibility
- Global climate change.

In summary, the findings of the study reiterate the need for the application of Mechanised Technology into South Africa's Bushveld UG2 narrow tabular orebody. These findings were congruent with those of Laflamme, et al. (2002). They posited the three objectives of a Mine Mechanisation and Automation Program are:

- **Health and Safety -** Enhancing both in underground mining operations
- **Mine Profitability** - Facilitating mechanization and automation to improve mine profitability
- **Science** - To provide sound science to regulatory agencies

6.4 Critical success factor of Mechanised Technology in to South Africa's Bushveld UG2 narrow tabular orebody

Objective #2

Investigate why Mechanised Technology as applied to South Africa's Bushveld UG2 narrow tabular orebody has always not been successful.

This objective investigates factors currently contributing towards the failures in mechanisation in the Bushveld Complex. The findings indicated there were eight Critical Success Factors (CSF) contributing towards failure. These were:

- Orebody characteristics
- Mine design and layout
- Mine logistics
- Lack of customised machines
- Mining machine size
- Machine utilisation
- Labour force structure
- Change management issues

Orebody characteristics.
These are the material and physical characteristics of an orebody. They include:

- Width
- Dip
- Regularity
- Planarity
- Overall dimension and amount of metal contained in the rock

There is a need to match the orebody with applied technology. Egerton (2004:439) states the undesired consequences of a mismatch between the orebody and the applied technology. Pickering (2007) makes the same observation and further opined that technology applied must be appropriate. This appropriateness is determined by the demonstration at the workplace that the intended functions are met, and the mining method selected is adequately productive.

A simple measure of “intended function” can be an ability to complete a planned mining cycle, within a planned time, within the stipulated specifications. At Union Mine’s 3 South Decline Section, high profile machines were utilised. The project suffered from excessive dilution because of the high-profile machine utilised. High volumes of waste and reef tonnes generated became uneconomic to tram with 20t dump trucks to surface because of excessive hauling distances. (Williams & Swanepoel, 2008). There was a mismatch between applied technology and the orebody.

Faulting is an orebody characteristic influencing how much waste development will be required for a stope face to be re-established back onto the reef. The degree of faulting has a material impact on the mining method and technology selection.

Union Mine’s Piggy Project is an example of where incessant faulting informed the decision to cease mining activities in that part of the mine, as well as the decision not to invest in the 5 South block of Union Mine. 5 South block stands unmined.

Mines designed and commissioned without due regard for orebody characteristics run the risk of having to convert to another mining method at a later stage. This conversion is often at great expense. At times, it becomes cheaper to shut down and walk away. Nong (2010) wrote about such failures at Lonmin and BRPM.

On July 2017, Platinum Group Metals Ltd issued a press release announcing the restructuring of their Maseve Platinum Mine. This restructuring entailed immediate shut down and cessation of all mechanised mining. Resumption of mining operations at a later date will be with a changed primary mining method. The redesigned method will use a selective mining method (Platinum Group Metals, 2017). Clearly, orebody characteristics influence design and lay-outs.

Mine design and layout

Mine design and layout were advanced by the respondents as one of the critical success factor. The design and layout of a mine must be compatible with the technology to be applied.

Designing the mine to incorporate a chairlift at Booysendal, Mototolo and Two Rivers Platinum Mines has enhanced the efficiency of people movement compared to Union, some Lonmin and Bathopele Mines which designed man carriers to transport employees to the working place.

Two Rivers and Booysendal designed main dip belts +/- 20m into the footwall. This provides surge feed on the dip belt, unlike the Union, Unki and Bathopele belt systems that rely on continuous feeds from strike belts. Invariably, these are non-operational at blasting and re-entry times. When strike belts stand, feed from underground also stops because of the lack of buffer ore feed.

Changing mining systems on an operating mine is not always successful. The existing infrastructure is not designed to support the change. For example, a shaft system not designed for trackless vehicle transport results in new equipment being disassembled for transport before it has even worked. The newly purchased, disassembled machines must then be re-assembled when they reach the desired level. See Appendices 6 and 7.

Mine logistics.

Logistics is an all-encompassing term for a variety of activities, equipment and infrastructure supporting primary production. The maintenance of equipment, movement of people and material are critical logistics which should be in place to effectively support mechanisation.

“What maybe sets them apart is the logistics. Bathopele mine should have had a chairlift. The people movement, even though it is a mechanised operation, there is a vast number of people that have to be moved. It is an interesting observation that Two Rivers Platinum and Booysendal Platinum have incorporated chairlifts in their designs”.

“One could use man transporters but those things are horrible. Chairlifts deliver miners, service personnel and supervisors at the face without having to drive up and down. It is inefficient. Walking up and down is even more inefficient. Workshops and layouts how do they impact on performance? How many machines ride up and down for dailies or for weeklies? What is in the original design? Are they designed to ride up and down? Daily checks, minor repairs and refuelling must be conducted underground. Weekly service and major repairs can be done on surface.” **RTP 1**

The above narrative, raised by Respondent 1, is affirmed by Webber, et al., (2010) and Rhodes (2015). These are pertinent logistical issues, which if not thought through and addressed during the design phase, have the potential to become severe bottlenecks, impacting on productivity of both men and equipment in a mechanised environment.

Not mentioned is the provisioning of:

- Swing units
- Auxiliary equipment for onsite roadway maintenance
- Vehicle recovery
- Belt position, arrangement and method of feeding it.

These are necessary logistical requirements which provide a mine with operational excellence.

Lack of customised machines.

The lack of customised machines creates an impression of overall failure of Mechanised Technology. Customised machines are fit-for-purpose and the ideal size in all operational respects.

Gilliani & Butt (2009) state that while civil engineering projects have greatly benefited from mechanical excavation of hard rock, mining on the other hand is still searching for a major breakthrough to modernise, mechanise and subsequently automate the winning of ore (stoping) and the development of access excavations.

According to Petit (2006), UG2 has a UCS of 110 to 120 MPa. Abrasivity as measured by the Bit Wear Index and determined by the Vickers hardness number rock (VHNR) is 400 to 610. Commercially viable machines, able to provide the energy required to overcome these variables without components failing, have yet to be developed.

The industry must continue to collaborate with OEMs in pursuing non-explosive technology.

Mining machine utilisation.

Poor machine utilisation arises when a machine is available for productive work, but is not used.

There are many reasons for this. Badly designed mining cycles create a conflict of activities resulting in machinery having to wait for a preceeding activity to be completed. Lack of adequate equipped face length results in machines not being fully utilised. Ideally, every fleet must have a redundant bord section.

"Our flagship mine does not have enough face length. What face length do the mines have? What is the economic limit of face they can have to get ahead of the advantage line in terms of face availability? One of the big constraints is face. The next big one would be the working hours." [RPT1]

Other reasons for poor machine utilisation are:

- The failure of one unit with no swing unit disrupts the entire cyle. The unit of availibility is per fleet and not the individual unit in the fleet.
- Work attendence. Operators not reporting for work costs the business as the machines will lie idle generating no revenue.
- Shift changes. Changing from working 3 eight hour shifts to 2 twelve hour shifts reduces dead time caused by shift line up, pre-use inspections and delays generally caused by shift change over.
- Blast reduction. Reducing the number of blasts reduces dead time caused by re-entry requirements.
- Continious operations. Continuous operation work arrangements allows machinery to be continiously utilised where they would have been parked idle on Sundays and public holidays.

Work force structure

This is critical in mechanisation. There is a need to build a relationship with organised labour before and after new technology has been implemented. They are stake holders who should embrace technology and not view it as another ploy by management to replace people with machines.

Continuous Operations affects plant and machinery utilisation. Production shifts are increased with commensurate increase in output. It has never been a popular working arrangement, but it can be negotiated with organised labour.

Whenever change is brought about, it affects people and such change must be managed well. All stakeholders must be taken on board. Employees must be part of identifying and providing solutions.

Selection, recruitment, training and placement of people in a mechanised environment is critical. With a younger and more educated workforce on the job market, skills are becoming easier to impart. They come with no prior faulty learning. What they know and apply at the workplace is what we have taught them. They must continue to be mentored and nurtured.

Based on the above model, first world mechanised operations are successful. Operations in Zimbabwe have adopted this work philosophy and prove the point. The Eastern Limb south of the Steelpoort fault apply variations of this philosophy while Bathopele has just moved into a two shift cycle in the past year.

Change management issues.

Mechanisation requires employee buy-in. Vogt & Hattingh (2016) concur and explained that a prerequisite for successful technology and mechanisation implementation is a change in people.

At inception, the Western limb recruited from the gold mines. No interventions and change management processes were put in place. The result - militancy and other undesirable behaviours were imported as well. Vienna/Dover testing was not part of the work selection process. Education was not a requirement; all an employee had to do was tick pictures on a check list.

With enhanced training, and the gradual replacement of the older generation ex-gold miners, with a better educated younger workforce, work ethics have improved. Current modifications on machines in the Eastern Limb make use of operators who understand the limitations of the machines, and what is required to overcome the problems. People are part of the solution every step of the way. They are achieving great things with ordinary people.

6.5 Future benefits from successful implementation of technology and mechanisation

Objective #3

Highlight future benefits from the successful implementation of technology and mechanisation in current operations.

Central to these benefits, is the sustainability within the narrow tabular UG2 Bushveld Complex. Sustainability is achieved by the industry being able to safely mine in areas where there are geotechnical constraints.

Depth, heat, seismicity and general ground stability are all challenges facing today's miner. Channel width, stope width and content are operational mine terms defining the economics of the Bushveld Complex. The sustainability of this industry is threatened because of:

- Commodity prices
- Cost of labour
- Inflation
- Decreasing worker productivity
- Ageing mines, particularly in the western limb
- Availability of skilled workforce

The successful reduction in stoping width by using smaller, current technology, or other future technology, brings about an increased profit through reduced milling and treatment cost.

However, current mechanisation efforts are generating excessive waste. Unwanted generated waste is transported and processed through the metallurgical processes. It is finally stored at a Tailings Storage Facility. This adds to the overall cost of metal produced.

Pickering (2007) observed that the biggest drawback has been excavation sizes introducing large volumes of waste into the ore stream. Respondent 21 concurred.

"All the techniques that are being driven currently are trying to minimise that dilution aspect because bodies that are currently amenable to the current type of mining are getting fewer and fewer. There is no doubt that we are trying to minimise as an industry the amount of waste being mined. Also trying to produce rock cuttings or breakings that are smaller so that you use less energy down the line for the metallurgists." [RPT21]

Successful implementation of technology and mechanisation brings a different type of worker into the mining labour market. The industry will employ highly skilled, productive, knowledgeable workers who can be appropriately remunerated. While fewer people may be employed per production unit, other opportunities are created in different functions within the business. Retraining and reskilling will be necessary.

As operations become efficient, opportunities are created to open up new sections and new mines. Ore resources are plenty in the Bushveld Complex. The industry will also have to continue to develop new markets for its product. Mechanisation will benefit from the transformation caused by employing women, and people with disabilities, who were previously left out of the job market because of their lack of physical stamina and endurance.

In summary

In this chapter, the discussion of the findings was conducted with respect to the objectives of the study.

The need for application of Mechanised Technology into South Africa's Bushveld UG2 narrow tabular orebody was established.

The reasons why Mechanised Technology as applied to South Africa's Bushveld UG2 narrow tabular orebody has always not been successful were established. The study achieved this by determining the Critical Success Factors for a mechanised operation.

Future benefits from the successful implementation of technology and mechanisation in current operations were highlighted.

The findings were contrasted with the existing literature as discussed mainly in chapter three of this report.

In the next chapter, the conceptual model of the study based on the findings is presented. It draws conclusions and recommendations for both the platinum mining industry and academics.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

In chapter one the research problem of this research was presented which is recapped as follows:

> Continued failure of tabular UG2 mechanised operations to meet expectations has retarded the modernisation of the platinum mining industry. This has resulted in mining companies considering reverting back to conventional mining methods.

This problem was investigated using the three objectives presented in chapter 1 and discussed in chapter 6 after the related findings in chapter 5.

The approach to the analysis of these objectives was presented in chapter 3. It was explained that qualitative methods using phenomenology design were the most appropriate as they allowed for interaction with the experts in the field. This enabled experts to provide in-depth insights on the realities in the platinum industry and the mining methods as applied to the narrow tabular UG2 orebody.

These findings were presented in chapter 5 and discussed in chapter 6.

In this chapter, the conceptual model for developing an application of Mechanised Technology into South Africa's Bushveld UG2 narrow tabular orebody is presented. This is followed by the conclusions.

Thereafter, the limitations which must be considered when contextualising the findings follows. The final part of the chapter is the recommendations to the platinum industry and to the academia.

7.2 Model of Mechanisation in Platinum Mines

The high-level process flow of mining in the Bushveld Complex is shown in APPENDIX 13 (solid lines). This is regardless of the mining method applied (mechanised or conventional).

OREBODY - The mining process starts with the defining and classifying of the orebody. The characteristics of the orebody, as per Smith (2012), influence the mining method, mine design and layout for the mine.

MINE DESIGN AND LAYOUT – The mine design and layout informs which infrastructure is required for effective extraction of the orebody. Infrastructure supports mining operations.

INFRASTRUCTURE, **PEOPLE AND LOGISTICS** - Logistics is an all-encompassing term used for a variety of activities, equipment and infrastructure which supports primary production. Together, effective infrastructure, people and logistics are enablers for superior operational performance.

LOGISTICS

Logistics is further broken down into:

- **MOVE** which entails the movement people, rock and material.
- **MAINTAIN** deals with the activity of maintaining the equipment and the infrastructure required and necessary to support the mining activities.

PEOPLE are a key factor influencing the success of the mining activity (Willis & Ashworth, 2002).

- **SKILLS** - For people to be effective, their skills levels should be adequate.
- **HEALTH** - They must be healthy.
- **SAFETY** - The selected mining method must promote safety. The operation must support injury free mining.

- **AVAILABILITY** - There must be an availability of people willing and prepared to perform the tasks required to execute and support the mining activity.
- **ETHICS** - the ethics of the people must be aligned to the requirements of the business. These ethics must include reporting for duty as per the work schedule, looking after equipment that is provided by the employer for the purpose of supporting the mining activity, and a commitment to the business.

The findings of the study, which are reflected in APPENDIX 13 (dotted lines) show there are inherent gaps existing within the Bushveld Complex when transitioning from conventional to mechanised mining. These gaps influence the success or failure of mechanised mining. There is a need to attend to and close these gaps to enhance the success rate of mechanised mining. The model attempts to show these salient activities when applying mechanised mining. There were seven core gaps identified.

Gap1: Applied Technology - Orebody.

There is a prevailing gap between the technology applied and the orebody. The orebody and its characteristics are not always compatible with the selected mining method and technology applied. The reef is at times too narrow, the orebody is too steep or it is too hard or abrasive as normally found in the Bushveld Complex. At times, it may also be a combination of all these factors.

Gap 2: Mine Design and layout - Mining.

The mining layout does not support effective and economic mining.

Examples include:

- Bord lengths - when they are too short, they are sub-optimal and uneconomic and when too long, they are unsafe as they are susceptible to collapsing.
- Vehicles - not having a free flow of vehicles when transporting ore underground creates unnecessary bottlenecks within the logistics of the mine.

- Dip belts - decisions on the placement of dip belts is material to the productivity of the belt system. Providing a permanent buffer feed on the main production dip belt has a quantifiable impact on the entire production line's productivity.

These elements are addressed during the design phase of a mine.

See APPENDIX 13

Gap 3 Move - Mining.

Vehicles get in the way of each other during tramming operations. This delays the movement of ore. People walking to and from their working places is an inefficient and ineffective method of moving people. It also increases the potential for accidents between employees and machines, and interfering with the smooth running of the operation. The ideal is to get people off the tramming ways where vehicles are operating.

Gap 4 Skills – Mining.

Transitioning from conventional to mechanised operations requires adequate skills to operate and maintain trackless fleet. Selection, training and mentoring of workforce is paramount to the successful application of a mechanised operation. This is true for the executives, managers, supervisors, operators and maintenance staff.

Gap 5 Health and Safety – Mining.

Despite widespread commendations on the reduction of injury rates, lung related occupational diseases and the decrease in noise induced hearing loss, mechanised operations have their own unique set of health and safety concerns. Examples are:

- The severity of injuries
- Diesel being a carcinogen – The application of the European diesel emission standards is a good starting point.

- Kidney and female reproductive disorders caused by vibration - Power steering assists females to be able to operate underground vehicles.
- Musculoskeletal disorders - The challenge is still out there for the managers and OEMs to develop vehicles with seats and ergonomics that are friendly to use by both men and women.

Gap 6 Maintain – Mining.

Service personnel must be well trained and be afforded the opportunity to do their work.
The fleet must be on a planned maintenance program. Maintenance schedules must be kept up to date. Machine damages must be investigated and recorded. There needs to be statistical controls to manage the quality of preventative maintenance. Integral parts of planned maintenance which must continuously be computed and recorded include:

- Mean Time between Failure
- Mean Time to Repair
- Engine hours
- Percussion hours
- Tonnes per kilometre hour

Auxiliary vehicles are an essential part of the fleet in successful mechanised operations. Ensure that there are swing machines available to cater for in shift break downs and planned maintenance.

Service personnel must be provided with vehicles to travel timeously to breakdowns. They must have recovery vehicles to get stricken vehicles out of the way and to the workshops for repair.

Roadway maintenance as well as the provisioning of serviceable workshops are a must before commissioning trackless equipment.

Gap 7 Ethics – Mining

Trackless equipment is expensive and therefore cannot be left idle when operators are absent from work. Operators are required to take care of the machines they operate. Damage of company vehicles due to lack of skills, or as a means to settle labour disputes, can never be acceptable.

7.3 Conclusions

The most dominant mining method in the Platinum industry within South Africa’s narrow tabular UG2 Bushveld Complex is conventional mining. However, there is an increasing application of Mechanised Technology.

The reality is Mechanised Technology is showing mixed results. Some mines are reporting some success, while others are reporting challenges which, in some cases, has forced them to consider reverting back to conventional mining. Underpinning these challenges are factors requiring attention.

It can be concluded that the application of Mechanised Technology in mining South Africa’s narrow tabular UG2 Bushveld Complex is possible. It can be successful if the seven gaps identified in the conceptual model are effectively addressed and closed by the Platinum industry in collaboration with the OEMs.

7.4 Limitations

The findings, and the model of the study, must be understood within the context of the following limitations:

- The challenges of the technology in mining were limited to South Africa’s narrow tabular UG2 Bushveld Complex orebody, or a similar setting, and cannot be generalised in all types of mining and ore bodies.
- The model developed was based on interviews. Though saturation was reached, not all mining houses in UG2 Bushveld Complex participated. As such, there is the possibility of some factors not being included in the model which could influence the success of applying mechanisation technology in South Africa’s narrow tabular UG2 Bushveld Complex.

- I was not successful in securing the interviews with operations north of the Steelpoort fault as there appears to be a material difference between them and the very successful operations in the south of the Steelpoort fault, even though both are mining within the geography of the Eastern Limb.

7.5 Recommendations

The recommendations of the study were presented two-fold. Firstly, implications for platinum industry mining in UG2 Bushveld Complex and secondly, recommendations for the way forward for academics.

7.5.1 Implications for Platinum industry

Based on the findings and conclusions, the following recommendations are made for the Platinum industry.

- **Mechanised mining should be implemented as a system.**
  This achieves success by looking holistically at people, process and technology inside an enabling environment. Together, the four create a system which works together towards achieving an end goal.

- **Improved safety in trackless mechanised mining**.
  The findings of the study were in agreement with the literature by (Webber, et al. 2010). According to them, health and safety within the mechanised operations have performed relatively well when compared to the conventional operations. This is one of the main motivators for mechanisation as underground mines are inherently risky because the operating conditions can be dangerous.

  Despite these positives, machine design issues are creating unintended health and safety risks. This provides challenges and incentives to managers and OEMs to address these design flaws.

- **Customisation of trackless fleet to suit UG2 Bushveld complex**
  This has been brought about by the unique orebody mined in South Africa's Bushveld Complex. While others have given up, the Eastern Limb, south of the Steelpoort fault, has persevered and successfully continues to make changes, customise and adapt supplied machines to suit their local conditions. It is recommended that the rest of the operations within the Bushveld Complex understand their specific conditions and innovate to satisfy their conditions.

  Waste sorting, stowing and dense media separation are old techniques, methods and technology which are being adapted to deal with waste generated underground as a result of reduced reef channel widths compared to the vehicle dimensions.

- **Change management to enhance employee buy-in on mechanisation**
  Without the necessary effort to win the hearts and minds of stakeholders, there is no likelihood of success of new technology. This is in agreement with the literature of Willis & Ashworth (2002) who posited that people are the key to successful technology transfer, as people and not papers transfer technology. People in the transfer process must be informed about the process, consulted about their needs, concerns, perceptions, attitudes and expectations. They must be trained and mentored to completely understand and utilize the technology to its fullest extent.

- **Leverage technology for mining gender transformation**
  Technology has provided women with a tool to compete with their male counterparts in the work environment. In a country like South Africa, where the inclusion of women in the workplace has been legislated, technology and mechanisation has been the vehicle for this transformation in mining.

  Mechanisation has facilitated the transformation of the workplace with no compromise to quality and efficiencies. Because of this success, the total labour pool has increased. This has been brought about by the inclusion of all adult gender into the labour market.

It is therefore recommended that management place maximum effort to ensure success of mechanisation so that gender equity can be achieved.

- **Current initiatives in robotics must be encouraged**
  This is innovative and breaks with the traditional sequential drill, blast, clean and support way of working. The coal mines have been successful by adopting a non-explosive philosophy.

  While the nature and characteristics of the Bushveld Complex rock is different, trials are currently on-going. The platinum industry is now learning and importing ideas from other disciplines and applications.

7.5.2 Recommendations for future studies

This research, like any research, had a scope of study, emerging insight and limitations. These are normally some of the key factors which enable the researcher to develop recommendations for future research. In this study, the following recommendations are made for future research:

- **Comparative studies of Eastern and Western Limbs.**
  As the Bushveld Complex, the Eastern and Western limbs have had different success rates in the mechanisation of their respective operations. It is recommended comparative studies be conducted between the two geographies so as to draw learnings on similar and differing success factors. The cross learnings will provide effective customisation of technology for these geographical areas.

- **Validate the conceptual model.**
  This study has developed a conceptual model based on the empirical data collected. It is therefore recommended that gaps identified in the model are validated by developing an instrument similar to the one of service quality gap analysis model (Parasuraman, et al.1985)

  This is followed by a survey using quantitative research methods, where the empirical data collected will be analysed using Structural Equation Modelling (CB-SEM or PLS-SEM).

- **Capability assessment of developed mining technology**
  It is recommended there be on-going research on the fit-for-purpose technology capable of mining successfully within the Bushveld Complex. Innovative and adaptation of equipment which has made a positive contribution to the current drill, blast and clean sequential way of mining must however continue to be encouraged.

- **Non-explosive technology**
  There is a need to go beyond the blasting technology by developing and enhancing non-explosive technology using robotics to combat the current frailties of employees and energy conservation.

- **Role of the Industry and Government in Research and Development**
  Individual mining houses have taken the initiative for Research and Development of the application of Mechanised Technology to South Africa's Bushveld UG2 Tabular Orebody. This study recommends coordinated involvement by the industry and government in Research and Development work to take this industry beyond the next fifty years.

  These recommendations would further enhance the research within mechanisation using technology in the Platinum mining industry.

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APPENDICES
APPENDIX 1

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Tendaupenyu

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H17/06/53**
PROJECT TITLE	An investigation into the application of mechanised technology to South Africa's bushveld UG2 tabular orebody
INVESTIGATOR(S)	Mr P Tendaupenyu
SCHOOL/DEPARTMENT	Mining Engineering/
DATE CONSIDERED	30 June 2017
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	24 July 2020

DATE 25 July 2017 **CHAIRPERSON** ____________________ (Professor J Knight)

cc: Supervisor : Dr D Vogt

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

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

____________________ Signature

_____/_____/_____ Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

APPENDIX 2

Participant Information Sheet

Title of Study:

An Investigation into the Application of Mechanised Mining Technology to South Africa's Bushveld UG2 Tabular Orebody.

Good day, my name is Peter Adam Tendaupenyu. I am an M.Sc. (Engineering) student registered with The University of The Witwatersrand, Johannesburg. I am conducting research on sustainable underground platinum mining by the application of Mechanised Technology. I would like to invite you to take part in this study.

Your participation in this research will contribute to the knowledge about the sustainable exploitation of the biggest known world platinum repository.

Should you agree to participate in the study, I will undertake to conduct the interview at a time and location convenient to yourself. The interview will take 60 to 90 minutes.

You will have the right to grant or refuse permission to be Audio Recorded. With your permission, the interview will be audio recorded and documented.

Your participation is voluntary. You have a right to refuse to answer any questions which you feel uncomfortable with. You may discontinue your participation during the course of this study without any prejudice. Your responses to the surveys being conducted will only be used for research purposes. They will be treated in the strictest of confidence as your confidentiality will be guaranteed and your privacy respected. Your anonymity is guaranteed.

You will not directly benefit from participating in this study. You will not receive payment.

The research will be written as a Project Report and will be available online through the University.

Please feel free to contact me or my supervisor should you have any questions about the study prior to or during the time of the study.

Thank You

Adam Peter Tendaupenyu

Cel +27(0) 83 413 2724, e-mail:1539266@students.wits.ac.za

Supervisor

Dr Declan Vogt e mail declan.vogt@wits.ac.za

Tel +27 (0)11 717 7363

APPENDIX 3

Consent Form

Title of Study:

An Investigation into the Application of Mechanised Mining Technology to South Africa's Bushveld UG2 Tabular Orebody.

I ____ , consent to participate in the research project. I understand that this research is investigating sustainable underground platinum mining by the application of Mechanised Technology to South Africa's Bushveld UG2 Tabular Orebody.

I understand that:

YES	NO	My participation is voluntary.
YES	NO	I have the right to refuse to answer any question I am uncomfortable with.
YES	NO	I may discontinue my participation during the course of this study without any prejudice.
YES	NO	I will not be paid for my participation.
YES	NO	My participation involves being interviewed by a researcher.
YES	NO	Interview may last 60-90 minutes. This time may be extended with my permission.

YES	NO

Notes will be written.

YES	NO

My identity will be kept confidential, my name will not appear on the Project Report and my anonymity is guaranteed.

YES	NO

I understand that I have the right to grant or refuse permission to be observed and Audio Recorded.

This study has been reviewed and approved by the Human Research Ethics Committee (Non-Medical) of the University of the Witwatersrand, Johannesburg.

Name :

____.

Signature :

____.

Date :

____.

APPENDIX 4

Consent Form

Title of Study:

An Investigation into the Application of Mechanised Mining Technology to South Africa's Bushveld UG2 Tabular Orebody.

My Name is ______________________________________ .

I consent to participate in the research project. I understand that this research is investigating sustainable underground platinum mining by the application of Mechanised Technology to South Africa's Bushveld UG2 Tabular Orebody.

Circle one

Permission to be interviewed.

YES	NO

I agree to be interviewed.

YES	NO

I know that I can stop the interview at any time and don't have to answer all the questions asked.

Permission to observe you whilst interviewing.

YES	NO

I agree to be observed whilst being interviewed

Permission to be audio taped.

YES	NO

I agree to be audio taped during the interview.

YES	NO

I know that the audio tapes will be used for this project only.

YES	NO

My identity will be kept confidential, my name will not appear on the Project Report and my anonymity is guaranteed.

Informed Consent

I understand that:

1. My name will be kept confidential.
2. The information I give will be kept confidential and safe.
3. The name of my company will not be revealed.
4. I do not have to answer every question.
5. I can withdraw from the study at any time without prejudice.
6. I can ask not be audio taped.
7. All data collected during this study will be destroyed within 3 to 5 years after completion of study.

This study has been reviewed and approved by the Human Research Ethics Committee (Non-Medical) of the University of the Witwatersrand, Johannesburg.

Signature :

____.

Date :

____.

APPENDIX 5

SCHOOL OF MINING ENGINEERING

UNIVERSITY OF THE WITWATERSRAND

SCIENTIA ET LABORE

JOHANNESBURG

<u>An Investigation into the Application of Mechanised Technology to South Africa's Bushveld UG2 Tabular Orebody.</u>

<u>Interview Guide</u>

1. "…we continually discover technologies, which promise superior results than those currently employed. Yet when the time comes to deliver, the results achieved seem to fall short of our expectations" Farren (2002). What are your views on the above? Do you have experiences we can share?

   ……………………………………………………………………………………… ……………………………………………………………………………………… ……………………………………………………………………………………… ………………

2. Leonard – Barton (1992) observed that organisations have traditional core capabilities. She also observed that organisations have core rigidities that inhibit innovation. She further observed that as way of dealing with this paradox, when faced with implementation challenges, managers of new products tended to
   i. Abandon the new project and revert back to the old tried and tested methods.
   ii. Move projects to areas without same core capabilities and managers with a value system different to the original teams.
   iii. Adopt new technology in a new geography.

   Considering your own experiences in the Bushveld Complex what insights can you give on the above?

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   …………………………………………………………………………………………
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3. Porter (2014) said "…the industry wants to use machines as a silver bullet instead of developing new systems".
   How pertinent has this been on the mines you have been involved with? Discuss.
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   ………………………

4. How do you see Technology and Mechanisation facilitating the achievement of workplace gender transformation as well the accommodation of workers suffering from HIV? Discuss.
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   ………………………

5. What scope exists for the application of Mechanised Technology as the primary means of production in narrow tabular UG2 ore bodies in South Africa's Bushveld Complex?
   Can we share your experiences?

   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……….......................

6. Comparing employees in mechanised and conventional operations, what have been your observation with regards to prevalence of occupational diseases? Discuss.
   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……….......................

7. Comparing employees in mechanised and conventional operations, what have been your observation with regards to injury rates? Discuss.

   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……….......................

8. How have the people employed on the Bushveld Complex on UG2 operations contributed to the success/demises of modernisation and technology application?
   Can we share your experiences?

   ……………………………………………………………………………………
   ……………………………………………………………………………………
   …………………………………………………………………………………....
   ....

9. With the benefit of hind sight what is it that you would do differently to be assured of guaranteed successful application of modernisation and Mechanised Technology in the extraction of UG2 in the Bushveld Complex?

…………………………………………………………………………………………
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APPENDIX 6

Slinging Underground via a Vertical Shaft a Component of a Stripped Machine

[Source: Rhodes 2015]

APPENDIX 7

Re-Assembly of a Machine Underground

[Source: Rhodes 2015]

APPENDIX 8

High Profile 7m³ LHD Working Underground

[Source: Rhodes 2015]

APPENDIX 9

24 Ton Truck at 60 Level Main Station Tip

This vehicle was used on a narrow tabular orebody which according to Rhodes (2015:152) was designed at a channel width of 120 cm. This vehicle was loaded by LHD in appendix 8

APPENDIX 10

[Source: http://sandvik.fortuna-co.com/underground-loader-lh205l.html]
Accessed 20/12/17

Low Profile LHD. Similar and/or equivalent units currently successfully deployed in room and pillar operations.

- Back heights as low as 1.6 m
- Low profile mine production and development
- Extra low profile mine production loading with a XLP dozer and access drive development.

APPENDIX 11

Ultra-Low Profile dozer cleaning a panel

[Source: Fourie et al. (2014)]

This remote controlled dozer has been developed to clean stope faces that wold previously been cleaned by 55kw face scrapers. They have proved themselves in hybrid low profile environment where they feed the ASG cleaned by Low Profile LHD as in appendix 10.

Trials are ongoing with Ultra Profile mechanises to utilised on breast mining layout. Should concept be successful the loader will form of the mining fleet.

APPENDIX 12

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

Dear Mr/ Ms…………………………

<u>An Investigation into the Application of Mechanised Technology to South Africa's Bushveld UG2 Tabular Orebody</u>

Following the voice recorded interview I had with you, I have since transcribed the recordings. The transcription is as per attached.

As part of demonstrating rigour and credibility for the study, may you please indicate by signing below that the transcription is a true recording of the interview I had with you.

Regards

Peter Adam Tendaupenyu

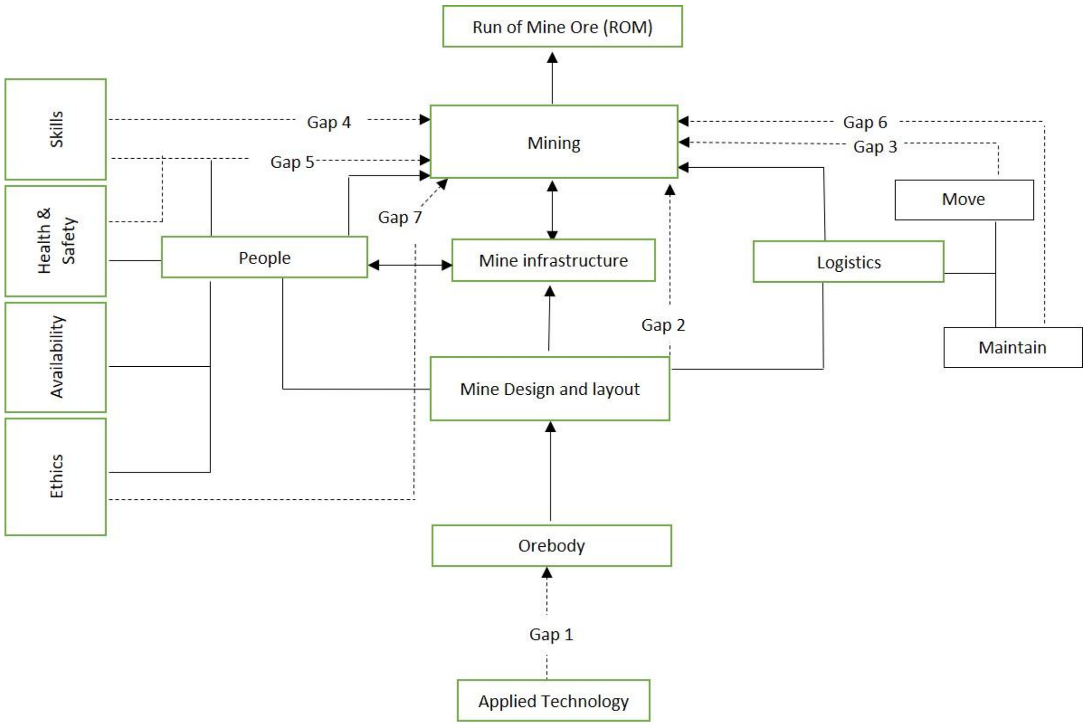
Student Number 1539266

I ....agree that the transcription is a true recording of the interview conducted between me and the Researcher.

Signed

....Date...

APPENDIX 13



Conceptual model for application of Mechanised Technology in mining. Solid lines represent existing critical process flows.

Dotted lines show gaps identified in this study which slow down the implementation of mechanisation [or whatever].