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UNIVERSITY OF THE WITWATERSRAND

FACULTY OF SCIENCE

SCHOOL OF GEOGRAPHY, ARCHAEOLOGY AND ENVIRONMENTAL STUDIES

THE IMPACTS OF THE FIFTH INDUSTRIAL REVOLUTION ON EMPLOYMENT IN THE GOLD MINING SECTOR IN SOUTH AFRICA

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June 2025

DECLARATION

I, Cebisa Sihlali, Student number: 81585, am a student registered for the degree of Master of Science in the academic year 2024at the University of Witwatersrand.

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ABSTRACT

The Fifth Industrial Revolution marks a significant evolution in technological progress, emphasising not only advanced automation but also the reintegration of human-centric values within the digital economy. In the context of South Africa's gold mining industry, historically labour-intensive and socio-economically sensitive, this study explores the workforce dynamics precipitated by the shift toward Human-Cyber-Physical Systems (HCPS). These systems represent a deliberate fusion of artificial intelligence, robotics, and human input aimed at enhancing safety, efficiency, and inclusivity.

Focusing on the modernisation journey of a major underground gold mining operation in the West Rand, Gauteng, the study employs a descriptive explanatory case study design. It draws on semi-structured interviews, site observations, internal company records and published to assess the adoption of 5IR-aligned technologies. Qualitative data were analysed thematically using Bingham's Five-Phase Analysis Process, while workforce transitions were modelled using a combination of logarithmic decay, sigmoidal growth, and Markov transition techniques. These modelling methods enabled the projection of job displacement, role transformation, and future skill demands over a 20-year period.

The findings reveal that although 5IR technologies create opportunities for safer, more agile, and more productive operations, they simultaneously accelerate job displacement, particularly among low-skilled and semi-skilled labour segments. A significant contribution of the study is the conceptualisation of "Operator X", a new construct that describes a vulnerable cohort of workers at risk of long-term exclusion from the digitalised mining environment due to limitations in skills adaptability, education level, or age. This group, which is often overlooked in policy design and workforce strategies, is shown to be most susceptible to displacement without a viable path to reintegration, posing risks not only to livelihoods but also to social cohesion and mine-community relations.

In response to these dynamics, the study introduces the Technology Map to Facilitate Mine Modernisation, a strategic framework for aligning technological deployment with inclusive human capital development. It also integrates the Strategic Workforce Planning Framework developed by the Academy to Innovate (2024), which provides a systematic approach to managing workforce transitions. This framework links workforce strategy with organisational

objectives, ensuring that transformations resulting from technological innovation are managed both effectively and justly.

The research further identifies a legislative gap in the South African mining policy landscape, namely, the absence of an enforceable framework to manage the socio-economic implications of digital transitions. Current labour and mining laws are shown to be ill-equipped to address the structural shifts brought on by 5IR, especially regarding proactive stakeholder engagement, skills transition mandates, and protections for displaced workers.

This study contributes new empirical and conceptual insights to the body of knowledge by: (1) modelling long-term employment impacts of 5IR technologies in a high-risk industry context; (2) introducing "Operator X" as a novel analytical lens for understanding exclusion in digital transitions; and (3) proposing actionable policy and industry-level recommendations to bridge South Africa's digital divide in mining. The study calls for urgent recalibration of workforce planning, regulatory alignment, and inclusive digital strategy to ensure that the mine of the future is not only technologically advanced but socially just and economically sustainable.

Key words: Automation, digital transformation, work force, operator X, 4IR/5IR and Mine of the future.

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CHAPTER ONE

INTRODUCTION

"AI technologies create less demand for human knowledge - and they put a premium on human wisdom" (Conley, 2024)

1.1 Background to the study

The acceleration of industrial revolutions has historically transformed the nature of work Ozdemir & Hekim, (2018). However, the transition from the fourth to the fifth industrial revolution presents an unprecedented duality: while it promises human-centric technological systems according to Rada, (2015), it also introduces new uncertainties regarding workforce displacement, digital exclusion, and structural inequality, particularly in labour-intensive sectors such as mining (Acemoglu & Restrepo, 2019; Karolia-Hussain & Fourie, 2021). What remains theoretically underexplored is how this human-machine convergence, especially in the form of Human-Cyber-Physical Systems (HCPS), will redefine employment hierarchies, skill demands, and socio-technical agency in resource-dependent economies such as South Africa. To better understand the context of this duality and the disruptive potential of 5IR technologies, it is essential to trace the evolution of this new industrial paradigm and its underlying principles. At the heart of this transition lies a radical reimagining of the relationship between humans and machines, exemplified by efforts to embed human agency within intelligent systems.

The concept of connecting robots to the human mind and having the inanimate working side by side with the animate is an intriguing idea, the reality of which has caught up with us sooner than expected Scanlon, (2018). This actualises the vision of incorporating the human factor into production systems. This is the Fifth Industrial Revolution (5IR). Conceptualised by Michael Rada in 2015, the 5IR represents the emerging successor to the Fourth Industrial Revolution (4IR) but does so with a heightened emphasis on human-centricity, sustainability, and resilience Rada, (2015). Whereas the 4IR focused on processes of automation and the reduction of human engagement in production, the intention behind 5IR is to reintroduce and reconnect humanity with advanced technological systems to mitigate fears of excessive dependence on robotics (Fanoro et al., 2021).

The 4IR, first introduced by the German Government in 2011, revolutionised industries by introducing cyber-physical systems (CPS), the Internet of Things (IoT), big data, and artificial intelligence (AI) to create interconnected, automated production processes (Javaid et al., 2023; Ustundag & Cevikcan, 2018). This shift reduced reliance on human physical labour by leveraging automation to improve efficiency, precision, and safety—particularly in hazardous industries such as mining (Jacobs & Webber-Youngman, 2017) (Jacobs & Webber-Youngman, 2017). However, this advancement also highlighted challenges, such as the displacement of human operators and the need for re-humanisation strategies to sustain workforce inclusion and adaptability (Voronov et al., 2020).

Historically, industrial revolutions have always disrupted the way humans work. The 1780s saw the First Industrial Revolution replace human labour with steam-powered machines, followed by the Second in the 1870s through electricity and steel production. The Third arrived in the 1970s with computerisation and basic automation, which transformed into 4IR through digitalisation (Ozdemir & Hekim, 2018). The 5IR builds on these advancements by emphasising the integration of humans into CPS, resulting in Human-Cyber-Physical Systems (HCPS) that prioritise both technological efficiency and human-centric values (Ruppert et al., 2019). These developments contributed to the gradual abandonment of physical, manual work and a shift toward mental and mechanical work (Dima, 2021). While the 4IR established the foundation of automation-driven systems, the 5IR refines these systems through enhanced human-robot collaboration and a renewed emphasis on human ingenuity. This marks the beginning of an era that not only seeks to overcome the technical challenges of automation but also addresses the socio-economic implications, aligning industrial progress with broader goals of human development and inclusivity.

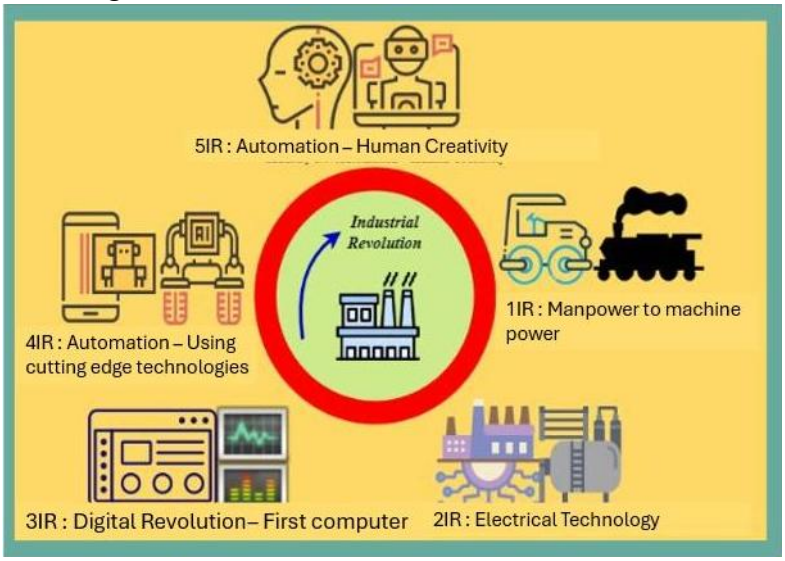
Globally, in the mining sector, 4IR technologies have brought especially disruptive shifts in both production systems and business models (Cook, et al., 2021) (Cook, 2021). Countries such as Australia and China have made significant strides in digital mining, employing AI for exploration and unmanned trucks in operations, with Russia and Brazil following similar paths (Voronov et al., 2020; Lugage, 2021).

In Sub-Saharan Africa, however, legacy challenges such as insufficient infrastructure, underdeveloped education systems, and limited technological capabilities have slowed the transition to 4IR, particularly within the mining sector (Ndung'u & Signé, 2020). Nonetheless, other sectors in the region have made notable progress. For example, Rwanda has pioneered the first drone port for medical supply delivery; Liberia deployed robotics during the Ebola crisis; and Nigeria has achieved notable advancements in digital service delivery. In the mining sector, Morocco and South Africa are among the continent's leaders. Morocco developed an autonomous proof-of-concept mining site, while in Ghana, Gold Fields introduced vehicle interaction technologies—including collision awareness and fatigue management systems, at its Tarkwa mine (Gold Fields, 2021).

In the South African context, deep-level, hard rock gold mines are now increasingly reliant on small, robust, trackless, and remotely operated machines to replace manual work in hazardous environments. As noted by the (Minerals Council South Africa, (2023), the vision is to remove workers from dangerous areas and upskill them to become machine operators. Through AI-enabled systems that can perceive and respond to changing underground conditions, these machines enhance both accuracy and safety. Initially, the adoption of 4IR technologies in South African gold and platinum mines was hampered by the complexity of deep geology and the high cost of modernisation (Ruppert et al., 2019). Nevertheless, the country has made significant strides in mechanisation (Macnamara, 2022). Although adoption varies regionally, the progress in South Africa and other African nations reflects the transformative potential of digitalisation and a gradual shift toward 5IR technologies that prioritise sustainability and inclusivity (Dannouni et al., 2020).

Considering these developments, this study seeks to investigate how the transition from 4IR to 5IR will impact employment, job design, and skill requirements in South Africa’s gold mining sector.

Figure 1.1: Evolution of the industrial revolution



Source: Adapted from Humayun, (2021)

Historically, industrial revolutions have always disrupted the way we humans worked. The 1780s saw the first industrial revolution replace human labour with steam-powered machines, and the 1870s the second industrial revolution brought electricity and steel production. The third came in the 1970s through computerisation and basic automation that transformed into 4IR through digitalisation (Ozdemir and Hekim, 2018). The 5IR builds on these advancements by emphasising the integration of humans into CPS, resulting in Human-Cyber-Physical Systems (HCPS) that prioritise both technological efficiency and human-centric values (Ruppert et al., 2019). These improvements contributed to the gradual abandonment of physical, manual work and a shift to mental and mechanical work (Dima, 2021). While the 4IR established the foundation of automation-driven systems, the 5IR seeks to refine these systems by advancing human-robot collaboration and placing greater emphasis on human ingenuity. This This marks the beginning of an era that will not only focus on overcoming the technical hurdles of technology and automation, but also the socio-economic impact they can have, aligning it with human development and inclusivity.

Globally, in the mining sector, the 4IR technologies have brought an especially disruptive shift in the production and the way business is conducted (Cook, 2021). Australia and China are notable examples of countries achieving considerable success in adopting digital mining practices, such as using AI for exploration and unmanned trucks in mining operations, with Russia and Brazil following suit (Voronov et al., 2020; Lugage, 2021).

In Sub-Saharan Africa, however, there are legacy challenges such as insufficient infrastructure, education systems, and technological capabilities that have slowed the continent's transition to the 4IR technologies, especially for the mining sector (Ndung'u and Signé, 2020). However, other sectors are also much further ahead, with automation and AI success stories already apparent in Rwanda, Liberia and Nigeria. Rwanda has created the first drone port in the world to reach difficult places and deliver medical supplies and goods. The world first tested this robot technology in Liberia against the Ebola virus (Salihu, 2018) which was tried in hospital rooms in Monrovia. In the mining sector, Morocco and South Africa stand out among leaders. Whatever it was, Morocco needed to serve its economic digital transition (Voronov et al., 2020), so it built an autonomous proof-of-concept site in real production. Additionally, in Ghana, Gold Fields has made advancements in vehicle interaction technologies, including the installation of collision awareness and fatigue management systems at its Tarkwa mine (Gold Fields, 2021).

In South African context, looking at the deep-level, hard rock gold mines, it is about simultaneously having affordable, small, robust, trackless and remotely operated machines do the sort of work that people have traditionally done. The idea, as proclaimed by the (Minerals Council South Africa, n.d.), is to keep miners out of dangerous places and train them to be machine operators instead. Further stating that artificial intelligence, or programmes knowledge which hopefully gives an equipment the ability to perceive its environment and take appropriate action to each unique condition, these machines can operate with narrow, confining workspaces, enhancing accuracy and productivity. South Africa initially encountered challenges in adopting the 4IR technologies within its gold and platinum mines. Factors such as the deep and complex geology of the mines and the high costs of modernisation hindered rapid progress (Ruppert et al., 2019). Despite these obstacles, South African mining companies have made significant strides in mechanising their operations (Macnamara, 2022). It has been observed that, while the adoption of the 4IR technologies in the mining sector varies across regions, the global and continental advancements underscore the transformative potential of digitalisation with South Africa and other African nations making steady progress towards leveraging innovation for a safer, more efficient, and sustainable mining industry, while gradually moving towards the integration of the 5IR technologies that emphasise human-centric and sustainable approaches (Dannouni, et al., 2020). Considering this observation, this

study aims to investigate the ways in which the adoption of the 4IR, advancing into the 5IR technologies, will impact employment.

1.2 Problem Statement

The impactful integration of Fourth Industrial Revolution (4IR) technologies, including automation, artificial intelligence (AI), and cyber-physical systems, has profoundly transformed industries worldwide, notably the mining sector (Zulu, et al., 2021; Karolia-Hussain & Fourie, 2021). In South Africa, these technological advancements have resulted in significant enhancements in operational efficiency and workplace safety. However, they have also raised substantial concerns regarding labour displacement, particularly affecting low-skilled and migrant workers (Maisiri, 2023).

Despite the establishment of initiatives such as the National Artificial Intelligence Institute and sector-specific AI hubs, South Africa lacks a comprehensive policy framework to guide the sustainable integration of emerging technologies with human labour (Mthombeni, 2025). Researchers argue that the absence of such a framework is especially problematic as the nation progresses beyond the 4IR.

Although there is increasing discourse on digital transformation, the implications of transitioning from 4IR to 5IR remain inadequately understood, particularly in high-risk and labour-intensive sectors like gold mining. Existing perspectives are often polarised, ranging from overly optimistic views of safety and efficiency improvements to pessimistic forecasts of widespread job losses, lacking sufficient empirical evidence (Adhikari, 2020). Furthermore, the adoption of 4IR technologies in the mining industry has been inconsistent, with numerous companies facing challenges due to infrastructural and financial limitations (Gonese & Ngepah, 2024).

Surveys and studies indicate that public perception, especially among rural and low-income communities, remains predominantly negative, with many perceiving automations as a direct threat to employment and economic security (Karolia-Hussain & Fourie, 2021). Nevertheless, these technologies also present opportunities for new forms of employment in data analytics, AI, robotics, and maintenance, provided there are deliberate strategies for workforce reskilling and inclusion.

Therefore, the lack of a policy roadmap, the uncertainty surrounding 5IR's labour implications, and the need to balance technological progress with human welfare, collectively present a pressing research gap. This study seeks to address that gap by exploring how digital transformation, specifically the transition from 4IR to 5IR, impacts employment, job roles, skills requirements, and workplace safety in the South African gold mining sector. The research will track workforce trends over a twenty-year period to determine how new roles emerge, how labour evolves, and what interventions are necessary to ensure inclusive and sustainable economic outcomes.

1.2.1 Research questions

In view of the above observation the following questions guided the research questions:

(i) What are the key factors influencing the adoption of modernisation initiatives in South African gold mines?

(ii) In what ways is technology deployed and how does the deployment of modern technologies, reshape the workforce?

(iii) What strategies and frameworks are currently in place or needed for workforce planning and reorganisation in South African gold mines to optimise task allocation and ensure a sustainable talent pipeline for both short- and long-term modernisation efforts?

1.3 Research aims and objectives

The study is aimed at investigating how the adoption of human centric the 5IR modernisation technologies is impacting the workforce in the South African gold mining sector over a twenty-year period, focusing on employment conditions and trends illustrating these changes on a time-based matrix. In view of this, the following were the objectives of the study, to:

(i) Examine the key factors influencing modernisation initiatives in South

(ii) Assess how technology is deployment in South African gold mines and determine how it reshapes workforce.

(iii) Evaluate the strategies and frameworks for workforce planning and reorganisation in gold mines, assessing how they optimise task allocation and ensure both short-term adaptability and long-term talent sustainability.

1.4 Theoretical considerations and literature review

The World Economic Forum (WEF) has formed an important part of the discourse surrounding the digital transformation, especially in its more industrial contexts. Important milestones for policymakers and stakeholders are its Digital Transformation Initiative (in 2015) and the 2017 White Paper on digital transformation within the mining and metals industry. It has given us an all-encompassing reference point for analysing and progressing digital transformation across industries. In particular, the White Paper highlights four fundamental areas of digitalisation in the mining and metals sectors:

(i) Automation, robotics, and operational hardware,

(ii) Digitally enabled workforce,

(iii) Integrated platforms and ecosystems,

(iv) Next-generation analytics,

This underscoring the transformative potential of the 4IR as a paradigm that equips industries with essential tools for innovation. However, it also points to several obstacles to being adopted across the spectrum, including prohibitive implementation costs, a lack of standardisation, and skills deficits.

Despite tangible recognition of the potential that the 4IR holds, fears remain over its unforeseen socio-economic outcomes. For example, Fierro et al. (2022) warn that automation and digital transformation may generate structural unemployment of a large magnitude, aggravating inequalities on the labour market. This view highlights the complex and multi-faceted transition processes to 4IR and Fifth Industrial Revolution (the 5IR) technologies. By contrast, Acemoglu and Restrepo take a more optimistic view, contending that, much as they did with historical technological breakthroughs, these transformations could drive up labour demand, generate new work, and raise wages. Their analysis indicates that the economic benefits of innovation can, under certain conditions, outweigh its disruptive effects.

The conceptual framework of the Fifth Industrial Revolution (the 5IR), introduced by Michael Rada in 2015, marks a decisive shift towards humancentric technological integration. Unlike the automation-focused the 4IR, the 5IR emphasises aligning technological progress with human needs and values, fostering what Rada terms a "humanised industrial ecosystem."

Supporting this vision, Saniuk et al. (2022) note that sectors and economies, particularly in Europe, have made substantial investments to advance the 5IR initiatives. These efforts aim to establish synergies between humans and emerging technologies while promoting innovation grounded in sustainability and social equity.

The adoption of such technologies is, however, shaped by a range of internal and external factors. Wang et al. (2021) identify operational challenges and strategic goals as critical internal drivers of technological adoption. Within the mining and metals industry, Shan et al. (2019) highlight additional complexities, including an ageing workforce, rising operational costs, declining ore quality, and increasingly demanding working conditions. These challenges illustrate the tension between the pursuit of technological innovation and the operational realities of industry-specific contexts.

On a protagonist note, Jacobs and Webber-Youngman (2017) predicted the pervasive role of technology in reshaping workplaces, emphasising its capacity to enhance employee productivity and transform organisational culture. They argued that prioritising workforce interests would be essential as technology continues to redefine operational norms. Similarly, Kagermann et al. (2013) urge for the need to marry innovations in technology with strategies for workforce development and to approach work organisation in an increasingly "smart" way. They argued that these changes will significantly impact the work itself, the way work is done and the environment in which it is performed in relation to flexibility, health care, demographics and work-life balance.

To frame these dynamics in the context of the mining sector, this study leverages two key theoretical constructs: The Technology map to facilitate the process of mine modernisation framework (the Technology map), as well as the Strategic workforce planning framework. Jacobs and Webber-Youngman (2017) created a Technology Map for research in this direction that acts as a model for integrating emerging technologies into the mining process. In line with this, the Strategic Workforce Planning Framework, developed by the Academy to Innovate (2024), provides a systematic approach to workforce transitions. Such a framework would link workforce strategies with organisational objectives, so that transitions resulting from technological innovation are managed both effectively and justly. These frameworks collectively furnish a comprehensive lens through which the intricacies of technological integration within the mining sector can be scrutinized. These inform the exploration of the

4IR and 5IR technologies, their contingents, and their implications on workforce dynamics including employment patterns, labour relations, and upskilling. A detailed discussion of these arguments is in Chapter two.

1.5. Methodological consideration

This section provides an overview of the research methodology which, according to Kashikola (2017), is a systematic investigation undertaken to generate new knowledge and bridge gaps in existing understanding. This researcher maintains that this approach guides the researcher in carrying out the project, dictating the tools selected.

The study adopts a critical realist philosophy and employs a descript explanatory research design. Non-probability sampling, specifically snowball sampling, is used to select interview participants. Data collection involves an iterative process using observation, case studies, and semi-structured interviews. The study population includes professionals from a large gold underground mining organisation in South Africa. Data analysis follows a five-phase qualitative analysis process, including organising data, sorting data into topical categories, open/initial coding, developing findings, and discussing findings. The study faced challenges in data collection due to the sensitivity of the subject, leading to a reliance on secondary data sources and a case study methodology complemented by interviews and observational data. A more detailed account of the methodological considerations is presented in Chapter three.

1.6 Scope of the study

The study examines the implications of adopting the 5IR technologies on employment, transitioning from traditional mining, in the largest gold producers by recovery rate in percentage and the number of tons of gold recovered. It covered the ways in which emerging disruptive technologies have the largest impact across the gold mining industry in terms of job evolution or replacement and the employment environment including health and safety job security. While the study considers operations along the entire value chain, from exploration, planning, design/construction, operation/productivity (which comprises both underground and surface operations), mine decommissioning and post closure, it is limited to the underground operation/productivity scenario. The geological setting of the study is restricted to the

northwest rim of the Witwatersrand Basin in the West Rand region, Gauteng province, South Africa, where gold producers extract the deep gold reefs of the Witwatersrand Supergroup, withing the South Deep Gold Field.

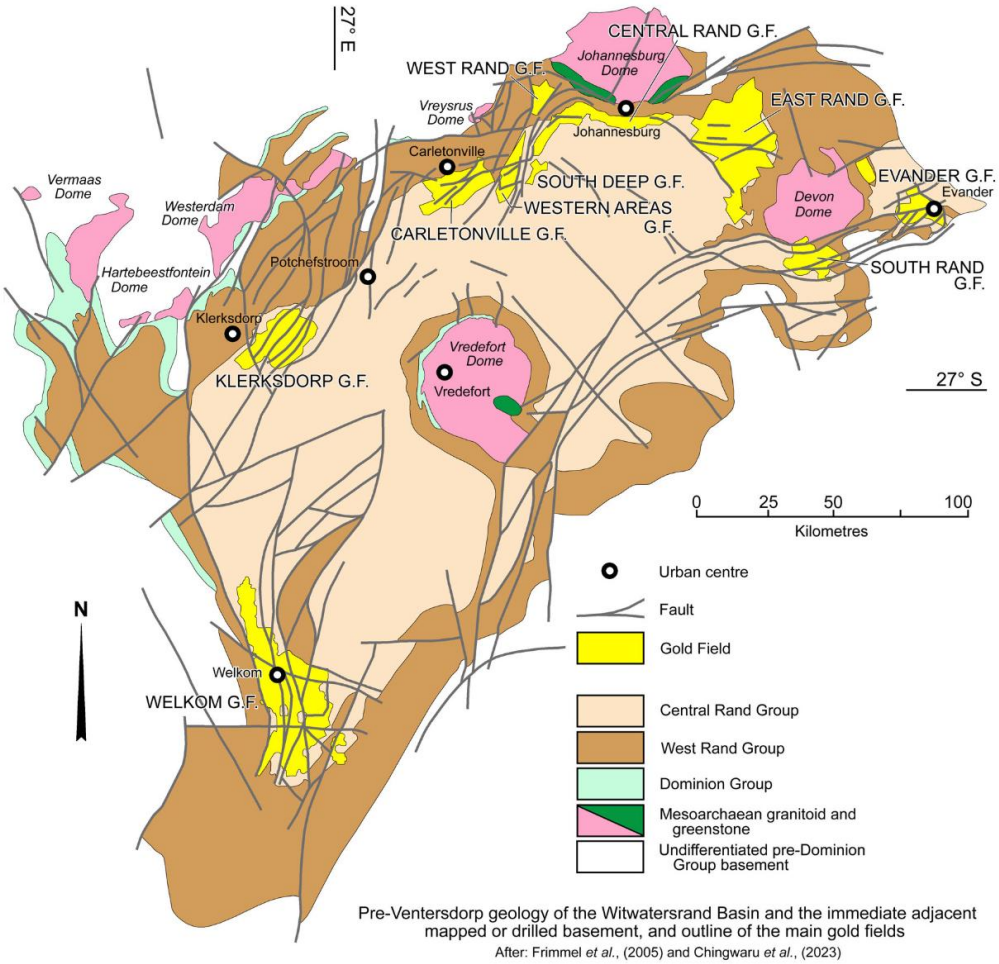


Figure 1.2: Geological map of the Witwatersrand Basin, showing the main gold field of the West Rand

Source: Gold Fields, (2025)

1.7 Ethical considerations

Ethical considerations are paramount in this research to ensure participants' rights are protected, which involves obtaining informed consent in line with ethical guidelines. Guided by these guidelines, the researcher adhered to the principles of beneficence, non-maleficence, autonomy, justice, and fairness. as outlined by (Varkey,2021). The researcher provided participants with information about the study's purpose, their required involvement, and any

potential risks or benefits. She gave them the opportunity to ask questions and clarify concerns, obtained informed consent in writing, and allowed them to withdraw at any time. The researcher respected participants' privacy and confidentiality throughout, keeping their personal information secure and limiting data access. She informed participants about data usage and removal of identifying details before analysis. The researcher stored all data securely and will destroy it when no longer needed. No vulnerable populations were involved, and no incentives were offered. The researcher conducted data analysis and reporting objectively, accurately disclosing limitations and potential ethical concerns, while acknowledging constraints on the study's generalisability. Throughout, the researcher considered all ethical aspects, informing participants about the study's purpose and their rights.

1.8 Structure of the dissertation

This dissertation structure comprises six chapters whose primary contents are presented below:



Chapter 1: Introducing the study and conceptualising the 5IR framework, highlighting it human centric shift from automation heavy 4IR framing the research problem



Chapter 2: Reviewing theoretical perspectives, including The Technology Map and "Strategic Workforce Planning Framework," and identifying gaps in the literature



qualitative method based deductive approach's descripto-explanatory research design, and data collection techniques and tools like multiple case holistic case study, interviews and observations. Data analysis and methodological reflections



Chapter 4: Presenting research findings, supported by tables and graphs, emphasizing 5IR's workforce and technological implications.



Chapter 5: Analyzing findings within the context of existing literature, highlighting key alignments, divergences, and insights.



Chapter 6: Concluding the study with key findings, practical implications, limitations, and recommendations for future research.

CHAPTER TWO

THEORETICAL CONSIDERATION AND LITERATURE REVIEW

2.1. Introduction

Research on existing knowledge has been strengthened by the cumulative foundation of previous scholarly contributions (Snyder, 2019). Therefore, meticulous selection and utilisation of foundational literature are essential to ensure the quality of the research outcome (Moher, et al., 2009). The literature review plays a number of critical roles, including examining existing theories or evidence within a particular domain or judging the merit of rival theories (Transfield, et al., 2003).This chapter builds on these roles by providing a conceptual theoretical perspective and discussing the existing literature on the impact of the 5IR humancentric digital transformation on the labour force, a topic that has received considerable critical attention (Ruppert, et al., 2019).

Research in the field of automation and digital transformation initially centred on investigations into the 4IR continues and has since research in the domain of automation and digital transformation is ongoing and has also been concerned about what the transition towards the 5IR systems may mean (Rada, 2015). As this research progresses, it is important to highlight existing gaps. This literature review assists the researcher to understand the status quo of existing knowledge about 4IR and 5IR by synthesising and analysing new existing research undertaken by other scholars as well as indicate gaps and/or areas that require further investigation especially considering the transitional period from 4IR to 5IR (Paré and Kitsiou, 2017; Paschek, et al., 2019). This chapter intends to provide a fresh context for the known arguments so as to produce new narratives in relation to this field.

In view of the above, following an engagement with some key concepts, the chapter is organised around four themes followed by theoretical perspectives. Thereafter one moves from a global perspective to continental then a national one in this section. In this chapter, we will conclude with strategies for identifying gaps in knowledge. This is the part where we will offer the rationale of the present study.

2.2 Definition of Key Concepts

Humayundan (2021), contextualises the 5IR and takes a dive into its fundamentals by tracing its origins back to the technologies and philosophies of the 4IR, seeking some sort of resonance between the two. In line with this approach, this subsection intends to offer a thorough understanding of essential notions fundamental to the profiling of the multidimensional features of the 4IR. Special emphasis is placed on their individual implications for workforce evolution, examining how these revolutionary industrial models affect workplace dynamics, the skills needed, and human-technology interactions. The analysis shall be on the following aspects:

(a) The 4IR profiled through its enabling technologies and design principles

According to the World Economic Forum (WEF), the Fourth Industrial revolution has some factors that distinguish it from the previous industrial revolutions (WEF, 2017). The Fourth Industrial Revolution, as defined by the World Economic Forum, is characterised by the ascendance of digital transformation, digitalisation, as well as automation of manufacturing, ensuring a revolution based on efficiency. Also, according to Ustundag and Cevikcan (2018), aspects such as standardisation, dynamic and secure networks, miniaturisation as well as incremental mechanisation and general innovation define the 4IR concepts. They additionally mention that the 4IR integrates new technologies into the manufacturing systems which include technologies such as Cyber–Physical Systems (CPS), Internet of Things (IoT), Industrial Internet of Things (IIoT), big data and analytics, artificial intelligence (AI), digital twin, and machine learning to build increasingly intelligent, flexible, and connected production systems (Javaid, et al. 2023). To these, Ruppert, et al. add the Internet of Services (IoS), robotics, cloud and cognitive computing, and augmented reality (AR) are add-ons (2019). In addition, Ustundag and Cevikcan (2018) also classified the Blockchain technology, 3D printing and the cryptocurrencies into the 4IR technologies.

Based on Hermann et al., the features for describing the 4IR as four key design principles can be synthesised. The first of these is *interoperability*, meaning that all industrial machines, tools, and systems can integrate seamlessly through the application of the Internet of Things. It allows for seamless machine-to-machine communication, leading to improved connectivity and

coordination in manufacturing settings. The second principle is *information transparency*, the ability for computer systems to create virtual copies ("digital twins") of the physical world, including its objects and processes. The better visualisation of data enriched with more transparency offers decision-makers a broader understanding of current situations and real-time insight into what is happening, making better decisions and at a faster frequency. The third principle, technical assistance, is simply the deployment of newly computerised machines with artificial intelligence behind them to assist and augment human workers where they make more sense. Utilising these AI powered tools' computational ability and accuracy, organisations can improve the productivity and effectiveness of their people and free up the time for them to concentrate on more valuable activities. Finally, with decentralisation we mean the building of technical systems that can operate and implement tasks autonomously. This allows much more flexibility and responsiveness in industrial processes, where single components and subsystems can act almost independently from each other and adapt their operations to the changing state of the environment without requiring the presence of a high-level control system.

(b) The 4IR Digital Transformation in the mining and metals industry

In 2015, the World Economic Forum (WEF) initiated the Digital Transformation programmes. Subsequently, the WEF released a White Paper on digital transformation in the mining and metals sector in 2017, categorising the 4IR digital transformation for mining into four themes as illustrated below:

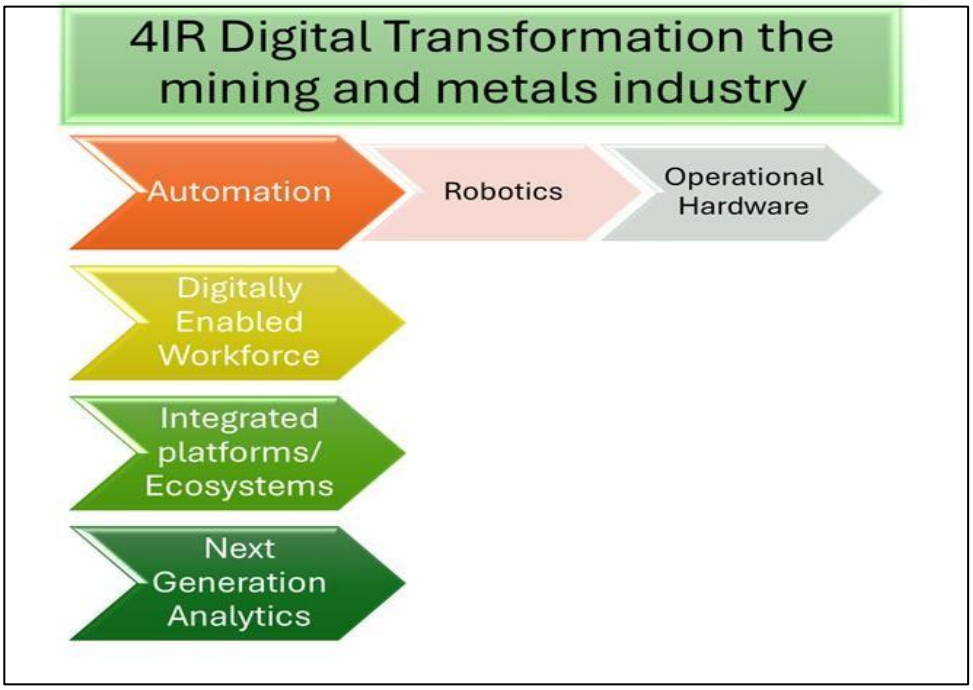


Figure 2.1: The four themes of digital transformation in the mining and metals sector
Source: Adapted from (WEF, 2017)

The implementation of digital transformation in mining operations provides many advantages of optimised operations ensuring that maximum performance is achieved, and a safer environment is created where the operator is not subjected to the hazards (Brune, 2019). Prof Fred Cawood describes digital mining as the integration of advanced technologies such as sensors, connectivity, and software to capture, communicate and analyse information about a mine's real-time conditions, its operations and people in order to improve safety and efficiency (Arnoldi, 2017). Hence there are uncertainties about transitioning to digital mining technologies, but this transition process from traditional production to smart production, accompanied by change management will lead to successful performance of digital transformation process (Fanoro et al., 2021).

(c) The labour dynamics aspects of the 4IR technological change

As the unfolding of the transitioning in production methodologies pursue with the progression from the first to the fourth Industrial revolution from manual to machine-based approaches, facilitating the emergence of smart industries (Ziatdinov, et al., 2024; (Ali, et al., 2022)). These

developments have systematically resulted in a diminution of reliance on physical, manual labour and a concomitant increase in dependence on mental and mechanical labour (Dima, 2021). This impactful change is encapsulated in the task-polarisation model by (Autor, 2022). The principle behind the model is that technological change redistributes tasks between workers and machines, shaping job opportunities and wage patterns because of automation and can directly replace human labour in specific particularly tasks. Autor, (2022) explains that these tasks, once well-paying, would now be fully automated, reducing the earnings potential for workers relying on such skills. These would encapsulate routine and codifiable activities like data entry, calculations, or proofreading. The model also reveals why technology tends to complement more educated workers. Tasks requiring abstract reasoning, creativity, and interpersonal communication such as leading teams, forming hypotheses, or making strategic decisions, are challenging to automate. These high skill tasks are enhanced by technology, boosting productivity and earnings for professionals like researchers, doctors, and architects. However, this has displaced many middle-skill jobs, such as clerical and administrative roles, as technology takes over routine functions.

On the other hand, Autor, (2022) explains, low-skill, manual jobs (e.g., personal care or food service) remain largely unaffected by automation due to their reliance on dexterity, common sense, and simple communication. However, these jobs typically offer low wages and limited career growth. Autor, (2022) concludes that, drawing from empirical evidence, this polarisation of job growth: high-wage, high-skill occupations are expanding, while middle-tier jobs are declining. This shift underscores the dual impact of computerisation, enhancing opportunities for some while diminishing them for others, thereby reshaping the labour market.

As this evolution proceeds, Ruppert et al. (2019) provide a profile of the worker who has had to evolve in order to remain relevant and create value while driving innovation, as highlighted by (Bradley and McDonald 2011). This is consistent with earlier observations by Drucker, who stated, "The true investment in the knowledge society is not in machines and tools. It is in the knowledge of the knowledge worker" (Drucker, 1959). Ruppert et al. (2018) illustrate the evolving role of the operator in production, in line with the evolution of the industrial revolution.

This is the categorisation of four generations of the operator, ranging from 1.0 to 4.0, according to (Ruppert, et al., 2019):

Table 2.1: (R)evolution of the tasks of operators in manufacturing systems

Category	Characterisations	Associated Industrial Revolution
Operator 1.0	Human labourers in a highly labour-intensive work environment utilising physical strength	First and second Industrial revolution
Operator 2.0	Humans utilising computer-aided tools and information technology systems	Third Industrial revolution
Operator 3.0	Robots, machines, and computer tools performing repetitive tasks, with the operator playing a supervisory role and applying cognitive skills	The onset of the fourth industrial revolution
Operator 4.0	The role of robots, computers, databases, and other information-intensive technologies is intensified, leading to extreme automation. The role of the operator is minimised to a remote one, which subsequently advances to an intensified collaboration with humanoid robots, and the operator is aided by cyber-physical systems	The maturation stage of the fourth industrial revolution advancing to the fifth.

Source: Adapted from Ruppert, et al., (2019)

Operator 4.0 represents a new set of solutions based on extensive cooperation between operators and production systems, depicting the future of the 5IR configured workplaces. The main elements of the Operator 4.0 methodology comprise:

Table 2.2 : The main elements of the operator 4.0 methodology

The main elements of the Operator 4.0 methodology	
Elements	Methodology
Analytical Operator	Employs big data analytics to collect, organise, and analyse large datasets.
Augmented Operator	Utilises augmented utilises to enhance the transfer of information from the digital to the physical world.
Healthy Operator	Measures and stores exercise activity, stress, heart rate, and other health-related metrics.

Smarter Operator	Interacts with machines, computers, databases, and other information systems, receiving useful information to support their work.
Social Operator	Utilises mobile and social collaborative methods to connect to smart factory resources

Source: Adapted from (Ruppert, et al., 2018)

(d) Transitioning into the 5IR

The 5IR has become a focal point of academic debate and technical anticipation as it endeavours to build upon the foundations laid by the 4IR. Interestingly, some researchers view the 5IR not as a stand-alone reality, but a continuation of the 4IR where new technologies are modifying industries, work efforts, and social realities (Humayun, 2021). Hence, the distinction between the two revolutions is often not clear, with 4IR technologies like AI, IoT and CPS forming the basis for the advances of the 5IR (Santhi and Muthuswamy, 2023).

Other scholars, such as Rada (2015), differentiate the 5IR as a paradigm where the understanding is machines no longer act independently but rather are built to expand human participation in decision-making. This reintroduction of the human element is an antidote to the 4IR trend of reducing human engagement in production systems. The 5IR has already begun affecting business landscapes (Atwell, 2017; Humayun, 2021), and in 2021 Gügerçin and Gügerçin (2021) were predicting that full materialisation will take place in another four years.

A critical aspect of this transition lies in Human-Cyber-Physical Systems
(HCPS). As a foundation for the Operator 4.0 concept, they guarantee that humans remain in the loop of industrial processes through increased transparency, real-time decision analysis, and collaboration (Ruppert et al., 2019). Moreover, HCPS are also compatible with the sustainability targets of the 5IR, emphasising human-based aspects as well as technological efficiency (Ozdemir and Hekim, 2018). Despite the advances made in digitization and automation, the mining sector represents a dual challenge between technology uptake and displacement of human labour (Voronov et al., 2020). Conclusively, the emergence of collaborative robots (cobots) and the 5IRbased technologies pave the way to a rehumanisation

of these systems by enabling seamless cooperation between the human and the machine (Ozdemir and Hekim, 2018).

This emphasis that is placed on re-humanisation the production space is especially relevant in the light of historical disruptions created by industrial revolutions to systems of labour. Human labour has historically been challenged from the steam-powered machinery of the 1780s to the digital revolutions of the 1970s. These revolutions brought about efficiency but also increased dependence on the human touch in production systems that were continually evolving (Cotten, 2009).

As 5IR emerges, this is targeted at improving human-robot interface design to enable a series of more ground-breaking and high-value usage scenarios of robots, especially those that exploit human creativity and problem cases (Fanoro, et al., 2021). This rehumanisation movement counterbalances longstanding worries about the domination of robotics over human operators, promoting inclusivity and adaptability in industries navigating ongoing transition. Industries can balance technological advancement with humancentric values through 5IR principles and technologies, enabling progress to be aligned with economic and societal goals. The interplay between sustainability, resilience, and human creativity is 5IR's most powerful developmental force, shaping the future of work and industry.

(e) The pillars of the 5IR

Humayun, (2021) explains that the 5IR integrates human expertise and machine precision to create sustainable, efficient, and user-focused manufacturing systems. She further adds that the 5IR is noted by as something that "adds a personal human touch to the two main pillars of the 4IR, automation and efficiency. the 5IR shifts focus from shareholder value to stakeholder value, emphasising the industry's role in contributing to society.

The key pillars are:

Table 2.3: The 9 pillars of the 5IR

Pillar	Characteristic
Human-Centric Design	Combines human ingenuity and craftsmanship with the efficiency, speed, and precision of robots. This fosters empowerment, talent, and diversity in the workforce.
Sustainability	Advances sustainable production through additive manufacturing (e.g., 3D printing), which integrates environmental benefits into goods and services while enhancing customer satisfaction.

Resilience	Enhances industrial robustness by ensuring systems can withstand disruptions and sustain critical infrastructure during crises. Resilience is achieved through effective human-robot collaboration.
Cost and Environmental Control	Smart, connected sensors and algorithms monitor and predict variables like climate, energy use, and temperature in real time, reducing costly mistakes and improving efficiency, particularly in weather-dependent industries.
Human-Machine Interaction	Promotes seamless collaboration between humans and machines, creating opportunities for advanced research, development, and operational synergies.
Quality Service Delivery	Enables high-quality services in remote areas, such as robotic-assisted surgeries in rural healthcare settings, enhancing access and outcomes.
Creative Freedom and Personalization	Facilitates the production of custom-made, personalized products, encouraging creative innovation and consumer satisfaction.
Automation	Simplifies and streamlines production processes, ensuring greater efficiency and scalability.
Higher-Value Jobs	Creates opportunities for individuals to focus on complex, high-value tasks, shifting from routine labour to roles that require creativity and responsibility.

Source: Adapted from (Humayun, 2021)

(f) The enabling technologies of the 5IR

The Emerging Technologies of the Industry 5.0 5IR technologies are the next stage industrial revolution technologies which centre around the core idea of human centricity, sustainability, and collaborative open innovation between humans and other advanced systems (Santhi and Muthuswamy, 2023). This subsection presents the key enabling technologies behind the 5IR and their capability to create intelligent, adaptable, and inclusive industries.

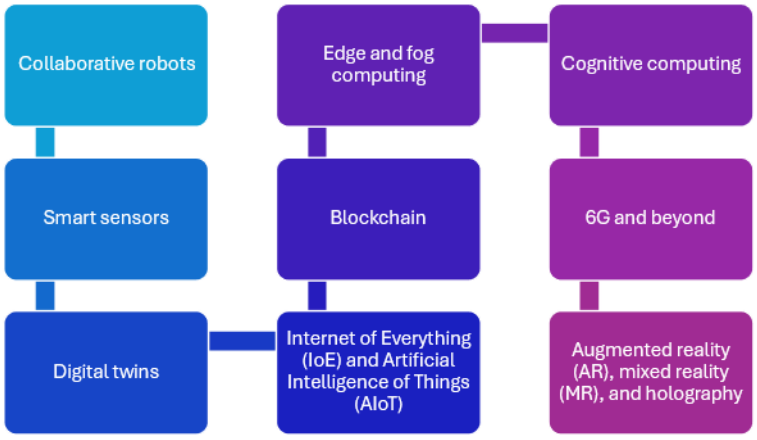


Figure 2.2: 5IR enabling technologies
Source: Based on (Santhi & Muthuswamy, 2023)

i. Collaborative Robots (Cobots)

As advanced robots working in coordination with humans instead of in isolation, the cobots phenomenon was defined by (Santhi and Muthuswamy, 2023). These researchers explain that, the cobots are different from traditional robots which are meant for specific tasks; they are adaptive to their surroundings, can learn on the go and work to cater to unique manufacturing requirements. They perform dangerous, repetitive work that allows humans to work with them to ensure production, assembly, material handling and quality control occur. Cobots, according to Santhi and Muthuswamy, (2023). are affordable, flexible, and offer competitive advantages to small scale industries, including increased productivity and lower costs. They give an example of cobots deployed in India's Craft and Technik Industries reduced repetitive manual labour and provided a 20% bump in product quality.

ii. Smart Sensors

Unlike traditional sensors that simply measure physical changes, smart sensors can collect and process data types, as well as communicate with external systems, such as cloud servers. They combine sensors, microprocessors, communication and memory modules, all in one module. Smart sensors serve as essential elements to the implementation of smart systems, making them relevant towards the advancement of Industry 5.0 technologies such as the IoT, CPS, and robotics (Santhi and Muthuswamy, 2023).

iii. Digital Twins (DT)

DT facilitate customisation, transform operations, mitigate errors, and promote innovative business models in the 5IR. They help discover technical challenges early, make accurate projections, and prevent financial losses. TD facilitates the remote update of physical systems and personalised virtual environments, while economic competition and improved client experience are enhanced with real-time data access and simulation impression models (Humayun, 2021)

iv. Edge and Fog Computing

Humayun, (2021) puts edge and fog computing into perspective by explaining that, in contrast, it helps mitigate issues associated with cloud computing, like high latency and high bandwidth consumption by processing data closer to the data source instead of sending data to cloud

servers. Edge computing handles data processing at or near IoT devices or gateways, and fog computing does so at LAN hardware farther from sensors. Both enhance response times and are optimal for real-time applications such as autonomous vehicles and healthcare applications. On one hand, cloud computing delivers high-end processing power, while edge and fog computing present low-latency, energy-efficient frameworks essential in the ambit of Industry 5.0. But, there are still some issues such as scalability, mobility support, and security need to be fixed for successful deployment.

v. Blockchain Technology (BCT) and the 5IR

5IR is all about diverse interconnected devices that are managed in a decentralised and distributed way, something blockchain technology promises to deliver on. It enables subscriber management on digital identities, which can mean controlled access and authentication for online industrial activities. These types of digital identities can also be used to manage properties, items and services; register intellectual property rights and automate contractual processes. These developments have resulted in typical blockchain markets that are expected to be worth USD 394.60 billion by 2028 (Future Market Insights – Blockchain Market, 2023) and also have highlighted the need for increasingly wide implementation of the financial industry of the blockchain to facilitate verified, secure, efficient, and automated transactions, thus forming the necessary support for the 5IR (Humayun, 2021).

vi. Internet of Everything (IoE) and Artificial Intelligence of Things (AIoT)

The Internet of Everything (IoE), a term coined by Cisco, takes the IoT further than just connecting machines and sensors to the Internet by seeking to also connect people, data and processes. IoE processes data acquired from connected wearable devices, smart appliances, and various other Internet of Things (IoT) devices with AI algorithms, helping make better decisions and improving productivity while decreasing costs and improving overall efficiency. Cisco believes that connecting the other 99.4% of unconnected physical objects will unlock the full potential of IoE.

AIoT is a technology that is both the combination of AI and IoT, allowing devices to analyse information, solve problems and make decisions on their own. AIoT embeds artificial intelligence algorithms into devices and systems and enables seamless interoperability between

them to increase the functionality of the systems without human intervention. It has a wide range of applications in smart homes, autonomous vehicles, industrial automation, and healthcare, highlighting its potential to transform various sectors (Santhi and Muthuswamy, 2023).

vii. Cognitive Computing

Cognitive computing, according to Santhi and Muthuswamy, (2023), refers to technology platforms which, when combined with machine learning models, can simulate human thought processes in a complex environment. AI, however, improves artificial intelligence algorithms to produce autonomous, accurate results, while cognitive computing adds to human reasoning by incorporating AI, machine learning, pattern recognition, and cognitive sciences. AI specialises in autonomous decision-making and self-correction, while cognitive computing assists human decision-making through contextual data interpretation and assumption-making. For example, it converts unstructured data (text, images, etc.) into insights.

They further explain that cognitive computing together with IoT forms "Cognitive Things" that can assist in making decisions after analysing massive data sets. Flash forward to 2025, when the same combination, enhanced by human intuition and ethics, will become vital to managing big data when 463 exabytes will be generated each day (Santhi and Muthuswamy, 2023).

viii. 6G and Beyond

This leads to smart infrastructure and next gen applications which brings out current network limitations. 6G and beyond will enable the 5IR by providing low latency service quality and providing a high degree of IoT (with AI capabilities) delivery. These forms of networks empower the 5IR through intelligent spectrum management, mobility, and connected intelligent environments. A growing number of smart devices contribute to an efficiency challenge, but optimised algorithms and energy-harvesting methods will create more sustainable 6G systems. 6G will be essential for governing large-scale data and enabling future innovations and paving the way for the 5IR towards human-centre and intelligent systems (Humayun, 2021), given that global data traffic is projected to be 5 zettabytes (ZB) a month by 2030 (Santhi and Muthuswamy, 2023).

ix. Augmented Reality (AR), Mixed Reality (MR), and Holograph

AR technology superimposes computer-generated images on a user's view of the real world to enhance the real world with digital information and virtual scenery. MR: The Micro Reality Mixed Reality combines elements of both the real and virtual worlds, providing real-time interaction with digital elements. Holography employs lasers to form accurate 3D images of objects.

Extended reality technologies are not the underpinnings of the 5IR but rather will be some of the key players in smart factories and digital adoption. They shorten lead times for product design, prototyping, and training while providing cost efficient solutions for distance collaboration and events (Humayun, 2021).

2.3 Contextualising the digital transformation in a global context

2.3.1 Drivers and barriers to digital transformation

Globally, the adoption of Fourth and emerging Fifth Industrial Revolution (4IR and 5IR) technologies in the mining sector has been driven by the imperative to enhance operational efficiency, improve safety outcomes, reduce labour costs, and promote sustainable production practices (Grabowska et al., 2022; Hajkowicz et al., 2016). Countries such as Australia and China have emerged as frontrunners in this transformation, supported by forward-thinking policy frameworks and substantial investments in digital infrastructure (Voronov et al., 2020; Wang et al., 2019). These favourable conditions have enabled the seamless integration of advanced technologies across mining operations, laying the foundation for enhanced productivity and competitiveness.

However, despite the evident potential of digital technologies, several structural and systemic barriers continue to inhibit widespread adoption. High capital costs, entrenched legacy systems, institutional resistance to organisational change, and acute shortages of digitally skilled labour remain persistent constraints (Wang et al., 2021; Shan et al., 2019). In the Chinese context, additional challenges related to interdisciplinary collaboration and ambiguous job descriptions have further complicated efforts to scale digital mining solutions (Shan et al., 2019).

Nonetheless, targeted foreign direct investment has catalysed skill-biased technological progress, stimulating innovation and increasing the demand for high-calibre technical personnel (Wang et al., 2021).

2.3.2 Technological Deployment and Workforce Restructuring in the digital transformation era

Among nations leading the technological transformation of the mining sector, Australia offers a compelling case study. The deployment of autonomous haulage systems, artificial intelligence (AI)-enabled exploration tools, and digitised control centres has redefined standards of productivity and occupational safety. In Queensland, AI-driven exploration has facilitated the economical discovery of ore bodies that previously went undetected, significantly lowering exploration costs and lead times (Lugage, 2021). At Gold Fields' Granny Smith mine, real-time monitoring technology has halved the time required to account for underground personnel, leading to marked improvements in safety and efficiency (Gold Fields Limited, 2019). Likewise, Rio Tinto's Pilbara operations and Fortescue Metals Group have successfully transitioned to unmanned haulage systems, consolidating Australia's reputation as a global leader in mining automation. These developments have been bolstered by strategic research commissioned by the Australian Department of Employment, which forecasted rapid shifts in workforce dynamics resulting from ongoing digital disruption (Hajkowicz et al., 2016).

In China, the digital transformation of mining has progressed through the adoption of the Mining Information Management (MIM) system, which integrates operational, business, and digital functions across the mine lifecycle (Wang et al., 2019). This digital architecture has facilitated streamlined decision-making, enhanced data integration, and increased operational agility. However, the transition has also necessitated significant workforce restructuring, as traditional job roles are redefined to align with the demands of increasingly technology-intensive work environments.

2.3.3 Workforce dynamics in the digital era

The restructuring of the workforce remains an unavoidable consequence of digital transformation. As mining operations evolve through automation and smart technologies, both

the nature and distribution of labour have been significantly affected. Acemoglu and Restrepo (2019) argue that while some technological innovations lead to gains in productivity, others contribute to declining labour demand, a reduced labour share in national income, and wage stagnation. In rapidly industrialising countries such as China, the shift toward advanced digital systems has triggered a sharp decline in demand for low-skilled, manual labour, while concurrently increasing the need for workers with specialised technical skills (Micic, 2017; Li et al., 2023). A similar trajectory is observable in Europe, where substantial investments—such as Germany's commitment of €40 billion annually to the ICT sector—have catalysed widespread digital adoption (Grabowska et al., 2022).

The transition to the Fifth Industrial Revolution (5IR) marks a critical evolution in workforce planning by introducing a human-centric ethos into technological development. Central to this paradigm is the integration of Human-Cyber-Physical Systems (HCPS), which seek to balance automation with human values, creativity, and well-being. In the European Union, 5IR has spurred the development of inclusive vocational education policies aimed at bridging the widening gap between rapidly evolving technological demands and the existing workforce's capabilities (CEDEFOP, 2021). These policy interventions are crafted to align human resource development with digital transformation, particularly in labour-intensive sectors such as mining.

According to Saniuk et al. (2022), strategic investments in human-technology collaboration are essential to ensuring that human potential is enhanced, rather than displaced, by emerging technologies. By fostering work environments where human skill complements, rather than competes with, automated systems, organisations can simultaneously achieve inclusive growth and operational excellence. This approach is particularly relevant to the South African context, where uneven digital infrastructure and fragmented training initiatives have left many workers vulnerable to technological exclusion.

2.4 Contextualising the digital transformation in a Sub-Saharan Africa context

2.4.1 Drivers and barriers to digital transformation

According to Maters (2021), Africa's historical relationship with industrial revolutions has been shaped by marginalisation and extractive economic structures. Masters traces the continent's industrial underdevelopment to colonial legacies that positioned Africa as a source of raw materials and cheap labour while excluding it from participation in knowledge-based innovation. As a result, much of Sub-Saharan Africa remains mired in the technological paradigms of the Second Industrial Revolution, even as the world advances into the Fourth and Fifth Industrial Revolutions. Masters (2021) argues that this historical inertia is a key driver behind Africa's limited readiness to embrace digital transformation.

Despite the immense opportunities presented by digital technologies, particularly the potential to leapfrog traditional development trajectories, Africa's digital journey has been hampered by significant structural constraints. According to the African Union's Digital Transformation Strategy for Africa (2020–2030), these include poor coordination among states, inadequate regional network infrastructure, limited financing, high resource costs, and widespread shortages in digital education and skills (African Union, 2020).

These barriers have curtailed meaningful participation in the global digital economy. Masters (2021) further observes that access to technological innovation remains concentrated among actors with capital and skills, thereby reinforcing existing inequalities.

Moreover, Africa's digital maturity is uneven and Dannouni et al. (2020) caution against treating the continent as a monolith, noting that levels of digitalisation vary widely across countries, sectors, and firms. Enabling factors such as technological infrastructure, governance capacity, and education systems diverge significantly. (Bakkar & Kaul, 2023)Bakkar and Kaul (2023) emphasise that one of the most persistent barriers to digital progress is the uneven distribution of digital skills, a theme echoed across multiple national assessments. Even within the mining sector, Metu et al. (2020) argue that automation levels are influenced by factors including national income, demographic trends, and industrial composition. Although countries like South Africa, Nigeria, Morocco, and Uganda have made notable strides in preparing for 4IR technologies, widespread scalability remains constrained by inadequate funding, policy fragmentation, and institutional weaknesses (African Development Bank, 2019).

2.4.2 Technological Deployment and Workforce Restructuring in the Digital Transformation Era

Evidence of technological deployment across Sub-Saharan Africa is uneven but growing. While South Africa leads in initiatives such as the South African Innovation Summit and several public-private partnerships in mining digitalisation, many countries remain constrained by limited financial resources and infrastructural bottlenecks (African Development Bank, 2019).

This technological lag is particularly stark in automation metrics. According to the International Federation of Robotics (IFR), Africa's robot density in manufacturing is dramatically lower than global averages. The world average stands at 126 robots per 10,000 employees, with Africa trailing far behind, contributing to its low performance on the Technology Achievement Index relative to other developing regions like South Asia and Latin America (Statista, 2024). As of 2025, projected robotics market revenues for Africa remain modest: US$124.2 million for Southern Africa, US$70.85 million for Eastern Africa, US$159.1 million for Northern Africa, and US$390.3 million for Western Africa. This collectively amounts to US$744.45 million, a figure dwarfed by the United States' projected revenue of US$10.45 billion (Statista, 2024). The continent's negligible manufacturing base for robotics and industrial automation technologies further underscores the need for strategic investment in digital infrastructure and skills.

Furthermore, structural differences in employment models also affect how automation unfolds in Africa. Wang et al. (2019) argue that Africa's labour markets differ markedly from those of developed economies, particularly in the mining sector. Unlike high-income countries where routine tasks are being automated to reduce costs, Africa's abundant and cheap labour means that digital transformation is not primarily driven by cost-efficiency but by external pressures such as foreign direct investment, compliance with global standards, and environmental risk mitigation. (McMillan & Rodrik, 2011)McMillan and Rodrik (2011) suggest that Sub-Saharan Africa is undergoing a nascent structural transformation, with employment gradually shifting from low-productivity to higher-productivity sectors. However, this shift is hindered by demographic pressures and underdeveloped labour market institutions.

2.4.3 Workforce Dynamics in the Digital Era

Sub-Saharan Africa's digital transformation is reshaping workforce dynamics, though in a fragmented and inconsistent manner. While automation and digitalisation create new skill demands, the continent's education systems and training institutions have been slow to align with the pace of change. This misalignment has led to a shortage of workers equipped for emerging roles in fields such as robotics, AI, and cybersecurity (Bakkar & Kaul, 2023; African Union, 2020).

The continent's workforce remains predominantly informal and low-skilled. Although digital technologies could generate new employment opportunities, particularly for young people, the continent's demographic bulge and slow-moving demographic transition compound labour market challenges. The result is a growing cohort of youth whose skills and aspirations are mismatched with the formal job market's digital demands (Metu et al., 2020).

In this context, digital diplomacy is emerging as a promising framework for Africa to navigate global competition and cooperation in the digital era. According to Metu et al. (2020), digital diplomacy enables African countries to explore collaborative initiatives—such as data governance frameworks, cross-border connectivity programmes, and space-based technologies—while also positioning the continent strategically within the evolving global digital order.

Digital diplomacy also plays a vital role in promoting socioeconomic development by creating forums for cooperation, knowledge exchange, and regional innovation. As Sub-Saharan Africa accelerates its 5IR agenda, Metu et al. (2020) argue that embracing digital diplomacy is crucial for ensuring that digital transformation contributes to inclusive growth and global influence.

2.5 Contextualising the Digital Transformation in a South African Context

2.5.1 Drivers and Barriers to Digital Transformation

In South Africa, the 4IR technologies in mining has been cautious and uneven (Zulu, et al., 2021). Gold and platinum mines have been slow to embrace digital modernisation due to a combination of geological complexities, high capital costs, and legacy operational structures. Nevertheless, progress is evident. Exxaro has made significant strides by investing in digital infrastructure and piloting a fully digitalised coal mine, setting a precedent for sectoral transformation (Slater, 2018; Creamer, 2016). In the platinum sector, the launch of a 5G-enabled smart mine through collaboration between MTN, Huawei, Nkwe Platinum, and Zijin Platinum reflects an effort to embrace intelligent mining technologies (Moore, 2022).

However, despite these efforts, South Africa lacks a cohesive policy framework to guide businesses through the digital transition while safeguarding labour stability (Karolia-Hussain & Fourie, 2021). The absence of this strategic direction leaves mining companies and workers vulnerable to the disruptive effects of digitalisation. As automation becomes increasingly central to mine operations, workforce displacement remains a growing concern (Ruppert et al., 2018). The high cost of modernisation, combined with insufficient reskilling initiatives, continues to present a substantial barrier to broad-based adoption.

2.5.2 Technological Deployment and Workforce Restructuring in the Digital Transformation Era

At the operational level, South African mining companies are beginning to implement advanced digital solutions. One prominent gold mine in the Witwatersrand Basin has embraced a comprehensive digitalisation programme, incorporating state-of-the-art technologies into its surface control centre to manage personnel, machinery, and environmental data (Macnamara, 2022). This facility, established in 2019, exemplifies a 5IR-aligned shift toward human-centric automation, aiming to relocate decision-making from underground to safer, controlled environments (Lööw, 2021). With the use of autonomous vehicles and remote blasting systems,

the mine demonstrates how South Africa is beginning to align its practices with global benchmarks in safety, efficiency, and sustainability.

Notably, there is considerable concern at the national level regarding the potential for substantial job losses due to the scale of automation. It is estimated that up to 41% of mining jobs in South Africa could be automated, particularly those involving routine and manual tasks (Adegbite, et al., 2021)(Adegbite et al., 2021). Nevertheless, there is currently no definitive policy in place to address the labour market implications of this transition (Karolia-Hussain & Fourie, 2021).

Macnamara (2022) foresees a challenging employment outlook, predicting that the modernisation of mining operations will reduce the demand for traditional labour, unless proactive skills development measures are taken. Supporting this, PricewaterhouseCoopers (PwC) anticipates around 87,000 mining job losses by 2026, with automation expected to displace up to 20% of roles by 2030 (Murray, 2021; Magwentshu et al., 2019).

2.5.3 Workforce Dynamics in the Digital Era

The evolution of labour in South Africa's mining sector must be contextualised historically. During the apartheid era, the gold mining industry employed as many as 800,000 workers between 1985 and 1990, underpinned by policies that exploited cheap black labour (International Labour Organisation, 2002; Casey, 2019). Labour unrest, exemplified by the 1946 African Mineworkers Union strike, was met with state violence and repression (Casey, 2019) (Casey, 2019). The late 20th century, however, marked a turning point: declining gold prices, reduced ore grades, and growing demands for better working conditions led to mass retrenchments and a structural reorganisation of the sector (Nattrass, 1995). By 1994, employment had fallen to 392,227 in gold mining alone, and by 2018, it had dropped further to 101,085 (Cawood, 2020). While the broader mining sector employed 454,283 workers by March 2024 (Minerals Council South Africa, 2024), the industry continues to experience waves of modernisation and restructuring.

The projected impacts of the 5IR, combining automation with human-centred values, remain a point of both hope and concern. On one hand, 5IR technologies may enhance safety, productivity, and sustainability. On the other, they are also expected to eliminate thousands of jobs unless retraining initiatives are scaled up (Young & Rogers, 2019; Adegbite et al., 2021).

In response, the Minerals Council South Africa (MCSA) has adopted a "people-centric," 4IR-enabled strategy that aligns with the ideals of the 5IR (Murray, 2021). The MCSA, as the peak industry body, advocates for policies that protect jobs while enabling innovation. Yet a sobering consequence of job losses is the growing trend of illegal mining, with displaced workers entering the informal and often dangerous “zama-zama” economy (Cawood, 2020; Minerals Council South Africa, 2019).

While forward-thinking companies have begun to deploy smart sensors and upskill workers for digital readiness, national labour laws and industrial policies have not kept pace. As Karolia-Hussain & Fourie (2021) assert, the legislative framework is outdated and insufficient for guiding the workforce through the 4IR-to-5IR transition. Despite these challenges, employment trends since the COVID-19 pandemic show signs of recovery. From a low of 344,737 workers in October 2021, employment rebounded to 454,283 by January 2024 (Minerals Council South Africa, 2024). This uptick may reflect broader economic growth and targeted recovery efforts. However, the mining sector’s long-term employment trajectory will depend on how well the industry balances technological advancement with inclusive workforce strategies. These developments underscore the need for responsive workforce strategies that align with the shifting contours of mining employment. Figure 2.3 illustrates the employment trends in South Africa’s mining sector between July 2021 and January 2024, highlighting both the volatility and the modest post-pandemic recovery trajectory.

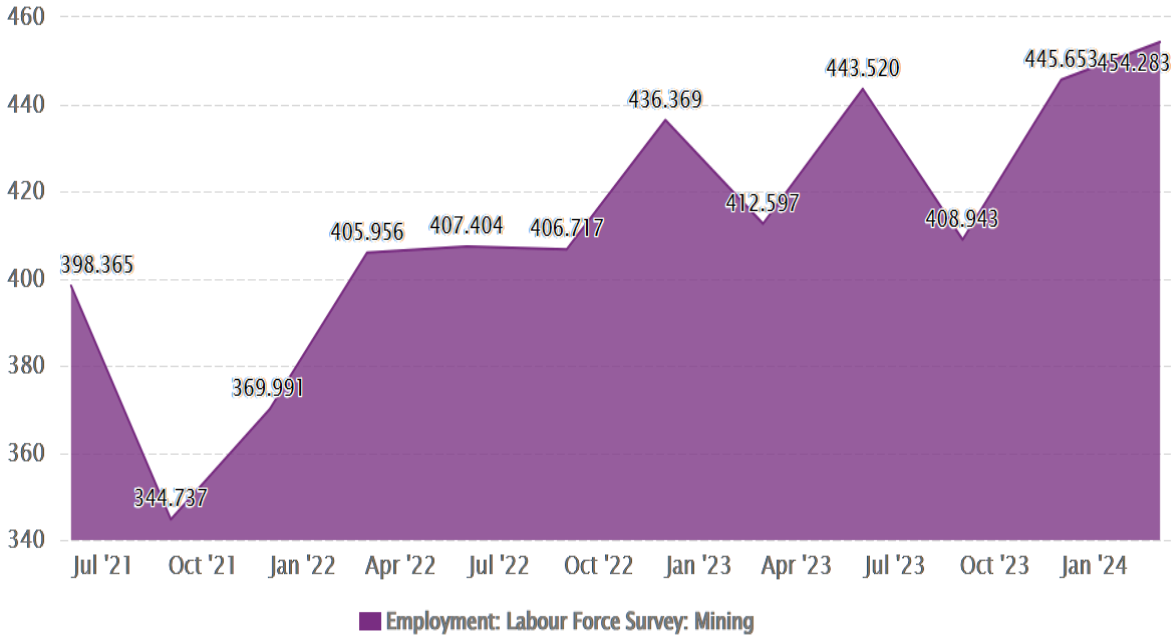


Figure 2.3: Trends in Mining employment in South Africa July 2021-January2024)

Source: (Statista, 2024)

2.6 Implications for the Labour Market and Research Gaps

The transition from the 4IR to the 5IR introduces significant structural shifts. Studies show that while automation increases productivity, it also risks exacerbating inequality by disproportionately displacing low-skilled workers and reducing labour's share of income (Acemoglu & Restrepo, 2019).

Within the South African context, the absence of up-to-date policies and institutional frameworks has left many workers vulnerable, particularly those in general labour and core skills categories. Forecasts estimate that up to 87,000 mining jobs could be lost by 2026 (PwC, 2024; Murray, 2021). At the same time, there is a paucity of research on the long-term employability of workers who cannot transition—referred to in this study as "Operator X."

Thus, a research gap exists in examining the longitudinal employment outcomes of HCPS adoption within South Africa's gold mining sector. This study addresses that gap by modelling the twenty-year impact of modernisation on employment, offering a time-based workforce evolution matrix that tracks job displacement, transformation, and creation.

2.7 Theoretical underpinnings on the 5IR and employment

According to Zulu et al. (2021), entrenching the 4IR technological adoption is imperative in the context of evolving production systems. This is a well-researched topic with numerous theoretical frameworks that elucidate the relationship between the 4IR and employment. A consistent theme across various disciplines highlights workforce changes, encompassing a

significant diversity of dimensions. Furthermore, the interconnectedness of the 5IR transitioning dimensions into the workforce of the future must also be considered (Santhi and Muthuswamy, 2023). These frameworks include and are not limited to World Economic Forum's "Future of Jobs" Framework (World Economic Forum, 2020), The Skills Framework for the Information Age (SFIA) framework (Skills Foundation for the Information Age, 2018), A simulation approach for planning and re-assigning of personnel in manufacturing (Zulch, et al., 2004), Workforce planning incorporating skills: State of the art (Bruecker, et al., 2015). Fit Viability and Task Technology Theory (Moreno,Jr, and Flavia, 2015), Skill Biased Technological Change Theory (SBTC) (Goldin and Katz, 1993), Disruption Theory (Terry, 2020), Mine Trainer Competency model, Development of a Competency Model for Selection of Human Resources in the Mining and Quarrying Sector in Bulgaria (Tepavicharova, et al., 2019). For the purposes of this study, we adopt two theoretical frameworks that are particularly well-suited to achieving the research aims outlined in Section 4.1. The first framework is the technology map, a mining industry specific framework proposed by Jacobs and Webber-Youngman (2017), which asserts that the exponentially increasing role of technology will fundamentally transform work content, processes, and environments. Building on this premise, Kagermann et al. (2013) argue that technological innovation must extend beyond the mere deployment of advanced systems to encompass the intelligent organisation of work and the continuous upskilling of employees. In essence, while the technology map framework highlights the structural changes driven by emerging technologies, Kagermann et al. emphasise that the successful implementation and assimilation of these innovations depend critically on a well-prepared workforce. Complementing this perspective, we also employ the Workforce Planning Framework. According to the Academy to Innovate (2024), effective workforce planning provides a robust foundation for managing human capital strategically. This framework guides organisations in aligning their talent strategies with overarching business objectives and is further supported by Zulch et al. (2004), who examine the dynamics of integrating technology and human operators in production systems. Together, these frameworks offer a comprehensive understanding of the dual imperatives of technological advancement and human capital development in the mine modernisation process.

Best practices in workforce planning, as highlighted by Bruecker et al. (2015), involve establishing precise strategies and schedules for hiring or restructuring talent, reallocating tasks from humans to machines, and determining the quality, quantity, and timing of these changes.

Moreover, the World Economic Forum (2023) stresses that contemporary talent management increasingly prioritises competencies such as dexterity, skill, and passion over traditional qualifications. Incorporating diverse skills and considering team dynamics, skill substitution, cross-training, and learning effects are vital elements of this modern approach. However, such endeavours are ineffective without a clear technology map to guide the evolution of the talent pool.

The factors discussed above provide vital insights into the successful and sustainable formation of a digitally empowered workforce in the mining sector. While numerous frameworks offer relevant insights, our focus is limited to those that directly inform our research questions. In doing so, we prioritise theories that provide the most valuable perspectives aligned with our study's objectives.

2.7.1 The technology map to facilitate the process of mine modernisation framework

Jacobs and Webber-Youngman (2017) assert that, as technological innovation in the mining sector is leading to a paradigm shift that focuses on productivity, efficiency, safety, and minimising environmental and operational risks. With that, they propose that, with increasing complexity in mining operations, organisations and individual mines should establish a structured approach to adopting emerging technologies throughout the mining lifecycle. They suggest that this requires a single access point for technology data on analysis, decision making, research, and development, etc.

The technological map for mine modernisation is presented in this section, as their work, which correlates technological solutions with the different stages of the mining cycle. These researchers prepared a detailed value drivers assessment across the mining life cycle with the technology road map incorporating both physical and digital technologies to realise operational efficiencies, operational gear with changing operational processes, to minimise operational surprises. They consist of four key enablers in technologies such as automation, artificial intelligence (AI), Internet of Things (IoT), advanced analytics, robotics, and digital twinning to enhance production, efficiency, safety, and reduction of risks, among others. Through these pillars, Jacobs and Webber-Youngman (2017) consider how disruptive and exponential technologies also play a part in the mining industry, so that mining operations can stay competitive and sustainable in a changing industrial landscape.

(a) The Need for a Technology Framework in Mine Modernisation

According to Webber-Youngman (2017), mine modernisation is not just the edition of state of the-art innovations, it is a systematic approach with the planned implementation of technology-based answers in the entire mining value chain. Their framework contributes to understanding how technology can be deployed at various stages of the mining cycle (exploration, project evaluation, mine design, operations, closure, and post-closure) where phase specific value drivers exist.

To create the technology map, these researchers analysed each mining phase, identifying the focus areas, phases, processes, activities and challenges for each phase, and determining the most suitable technologies to tackle these challenges. To assess each technology, five main factors were considered: Increasing production output, improving productivity and operational efficiency, maximising efficiency and cost-effective resource use, enhancing health, safety and environmental performance, minimising possibility of human errors and operation failures. Their view is that an integrated approach to data management means mining companies can make datacentric decisions as they steer toward a more sustainable, efficient, and future-ready mining operation.

(b) The Technology Map: A Structured Process

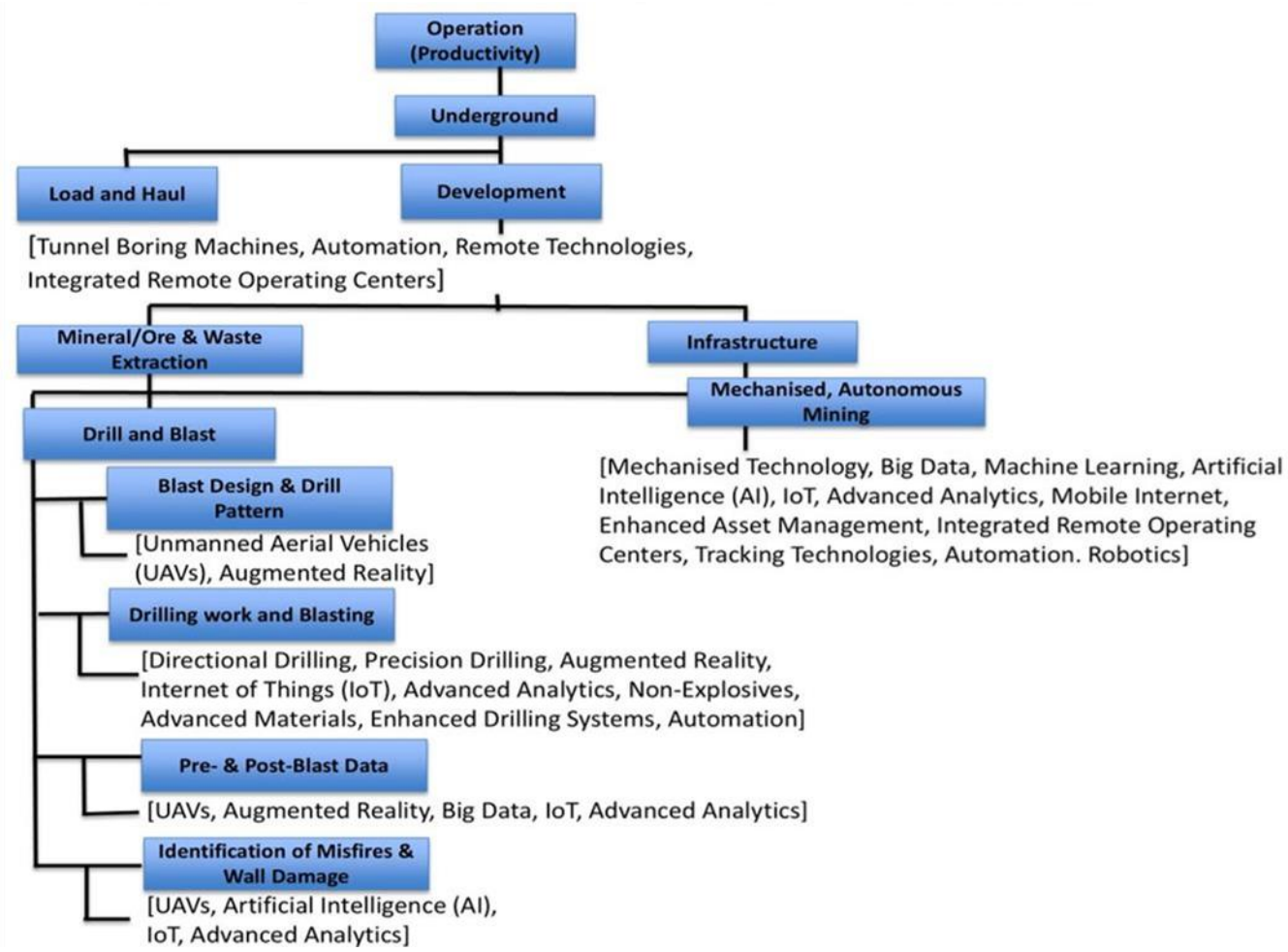


Figure 2.4: A Technology map to facilitate the process of modernisation for an underground mining operation - productivity stage
Source: (Jacobs & Webber-Youngman, 2017)

Webber-Youngman (2017), define the technology map as hierarchical in nature, aligning technological interventions with the stages of the mining cycle. An important part of this map to the researcher is the underground mining related activities, particularly development, extraction, and infrastructure that are part of modern mining.

The underground mining productivity model is divided into three core components:

(i) *Load and haul*: Tunnel boring machines, automation, remote tech, integrated remote operating centres, material handling and transportation. Automation, remote tech, integrated remote operating centres, material handling, transportation

(ii) *Development:* Ensuring that early-stage underground construction facilitates future automation, connectivity and digital integration.

(iii) *Mineral/Ore and Waste Extraction*: Utilising intelligent extraction methods to effectively recover essential minerals while reducing environmental impact.

(c) Modernisation of Drill and Blast Technology

For underground mining, drill and blast works are an essential part of this industry. The upgrade needs in this stage are:

(i) *Blast Design and Drill Pattern Optimization*: With the help of UAVs and augmented reality (AR), drill patterns can be planned and optimized.

(ii) *Drilling Work and Blasting*: Innovations like vertical drilling and directional, IoT-enabled, automated, and advanced analytics in blasting is increasing accuracy while reducing energy demand, and the rock is fragmented with non-explosive materials.

(iii) *Pre and post blast data analysis***:** Incorporating big data analytics, IoT, UAVs, and augmented reality to enhance real-time monitoring and decision-making.

(iv) *Detection of Misfires and Damage to Wall*: Using AI, IoT, UAVs, and predictive analytics for structural integrity and safety in the job site.

(d) Mechanised and Autonomous Mining Infrastructure

A fundamental pillar of mine modernisation is the shift toward mechanised, autonomous mining which integrates the following according to WebberYoungman (2017): advanced mechanized equipment, analytics with big data and machine learning, IoT-driven smart mining operations, Enhanced asset management systems, automated tracking and remote monitoring technologies and Robotics and autonomous equipment fleets

These technologies are designed to create an intelligent mining ecosystem, reducing the human interference in dangerous area and achieving efficient and better controlled operations.

(e) Technologies that are Disruptive in Mine Modernisation

In addition to automation and digital integration, Webber-Youngman (2017)'s framework considers several disruptive and exponential technologies that have the potential to redefine mining operations:

(i) *Cloud computing and edge computing*: Improving data accessibility, real-time decision-making, and remote collaboration.

(ii) *Blockchain for supply chain transparency*: Improving traceability and sustainable sourcing of minerals

(iii) *Renewable energy and energy storage* solutions: Decarbonised mining via solar, wind and battery technologies

(iv) *Additive manufacturing of equipment*: Facilitating rapid prototyping and site-specific parts.

(v) *Digital twins and virtual reality (VR):* Used to simulate environments for training, operational planning, and risk assessment.

Webber-Youngman (2017) assert that, integrating these technologies allows the mining sector to shift from a reactive to a predictive mode of operation, thus enhancing efficiency, minimising downtime, and creating a safer workplace.

The theoretical framework of mine modernisation here, as represented by the technology map, provides a systematic approach to integrating technology into the mining lifecycle. By mapping out technological interventions for each phase of mining, the framework enables a targeted, data-driven modernisation strategy that aligns with industry best practices. The hierarchical structure of the technology map covers both short-term improvements and long-term transformation goals. Youngman's framework allows companies to pinpoint specific technologies for further research and development and to customise solutions that align with organisational strategies and operational requirements. While the map itself offers a high-level overview, the authors caution that each company must design its system architecture according to its unique challenges, resources, and long-term objectives.

2.6.1 Refinement of the Technology Map to Incorporate Human-Centric 5IR Innovations

In order to systematically assess the impact of technological advancements across the mining value chain, this study employed the Technology Map Framework initially developed by Jacobs and Webber-Youngman (2017). The original framework provides a visual depiction of how various technologies are integrated throughout different phases of mining operations, from exploration to post-closure. Its structured layout allowed for a comprehensive examination of where and how technology is applied, especially as it relates to the drive for modernisation within the industry.

Building on the foundational work of Jacobs and Webber-Youngman, the author developed a modified version of the technology map tailored to reflect the specific innovations implemented by the mine under study. The original framework was expanded to incorporate emerging 5IR (Fifth Industrial Revolution) technologies, with a focus on human-centric approaches. These include systems that enhance safety, promote collaboration between humans and machines, and utilise data analytics and artificial intelligence in ways that centre the worker's role within the digitised mining environment.

Key additions to the map include the integration of IoT sensors, advisory systems, geofencing, collision avoidance systems, and mesh network communications, among others. These technologies not only optimise productivity and operational efficiency but also support safety, well-being, and environmental monitoring—hallmarks of 5IR philosophies. For example, the inclusion of human-machine interface technologies, such as remote monitoring platforms and wearable safety systems, signals a shift from purely mechanistic automation to a more inclusive and adaptive technological ecosystem.

Overall, the revised map demonstrates how the mine under study has moved beyond traditional automation strategies and toward a more holistic modernisation model that emphasises adaptability, sustainability, and human-centred design. This evolution in the technology framework provides a clearer lens through which to analyse the alignment between technological advancement and strategic workforce considerations in a modern mining context.

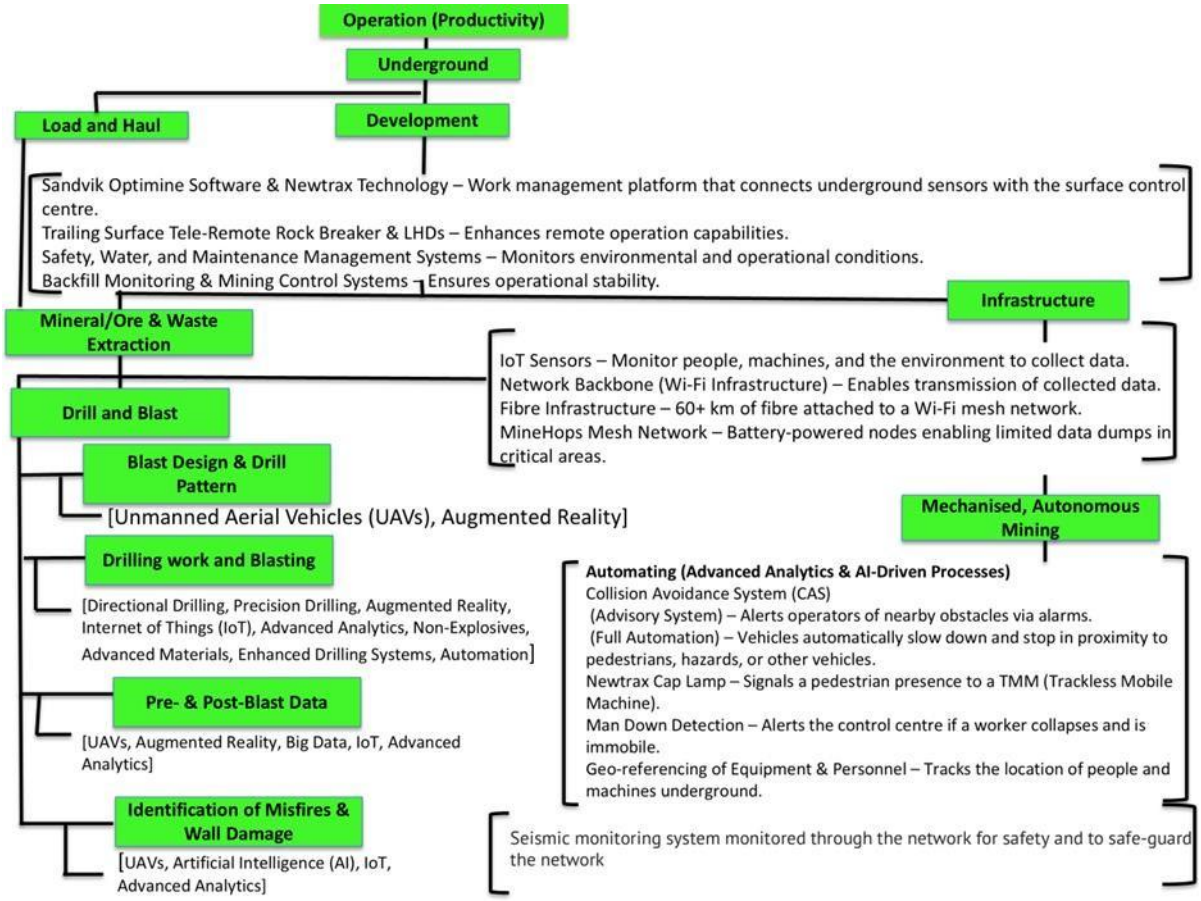


Figure 2.5: A customised technology map to facilitate underground mine productivity modernisation
Source: Modified by author Jacobs and Webber-Youngman, (2017)

2.6.2 The Strategic Workforce Planning Framework

The Strategic workforce planning framework offers a structure that can help organisations establish a sound process for workforce management. It helps steer the process and shows the way integrated workforce planning aligned with the strategy of the organisation can take the changing workforce in the right directions (Academy to Innovate, 2024). While the academy's framework is based on four steps: product (in this case, technology), organisational strategy, quality and quantity of workers, and HR strategy, Zulch et al. (2004) extend this by addressing the dynamics of integrating technology and human operators in production systems. This integration involves a range of challenging tasks, as outlined by Acemoglu and Restrepo (2019), such as the transformation of new skills, workforce adaptation, technology integration, organisational change, impact on employment patterns, and task allocation, which must balance skill requirements with skill availability. Recognising this shortcoming, Zulch et al.

(2004) has recommended that we must become adept at using sophisticated planning tools that enable flexible problem solving. Thus, the aim of developing a workforce-based framework is directed towards developing a workforce-based framework for integrating the production system so that intelligent workspaces can be established by incorporating the human lead time through workforce planning and scheduling. This gives the researcher a broader and more contextual view of the complex interactions that underpin workforce transitions in the age of the 5IR.

The framework for strategic workforce planning is built on three fundamental principles. The first one aligns with the strategy of the organisation. The second is the 80/20 rule, also known as the Pareto principle. Last but not least, staying long-term focused (Academy to Innovate, 2024). As per the academy, the first principle states that strategic workforce planning need to align itself to the organisation's strategy. While organisations do define their strategic contingents individually, Lööw (2021) references a particularly salient trend with respect to the mining field, namely, the visible common strategy of transitioning to changing workforce roles in the face of technological development. Consequently, strategic workforce planning should be guided by the organisation's digitisation strategy, which is the short and long-term plan that the organisation develops to establishes what the company aims to achieve over the next five to ten years. Lööw (2021) emphasised the need for continuous organisational and employee framework alignment to successfully respond to shifting skill sets required, as shown in the ideal transformation of conventional mining.

The second principle states that good workforce planning follows the 80/20 Pareto principle. In other words, 80% of the result is achieved with only 20% of the work put in. The quality and quantity of the skills pool inform this principle, implying that the company must establish measures for the success of modernisation efforts concerning the workforce, which is connected to strategic workforce planning, where the primary focus is on the organisation's critical roles. These are the ones which are inextricably linked to organisational outcomes. In addition to this, the organisation should have mechanisms in place to show that by looking at skills, leadership can see what is being gained from the learning and development budget in terms of the impact on business.

The final principle is the Long-term focus. Researchers like Zulch et al., (2004) support the case for long-term planning as the ideal planning horizon because in terms of flexibility, long-term planning facilitates gradual distribution of individuals into roles and functions that are part of intelligent workspaces. These areas of employment consist of humans integrated into cyber-physical systems (Team, 2022). Short term planning, on the other hand, provides less flexibility in planning re-assignment of workers who are present. If this is the case, the talent pool consists of the current pool of skills, and this is the reason why studies like Bruecker et al. (2015) reiterate that workforce planning and scheduling is essential. According to them, effective implementation will improve work force allocation and sustain long-term competitiveness. They highlight the vital need for workforce planning processes to be included in talent strategies and plans used.

To sum up this perspective provided by Bruecker et al. (2015), workforce planning, which includes staffing and scheduling, is a prominent part of the transition process. Organisations can estimate the number of workers needed and when they will work through staffing and scheduling, using predictive analytics tools. Organising work task allocation amongst various roles can be a great challenge in most of the corporate tiers at all levels and the predictive analytics-based approaches can be applied for overcoming this challenge systematically. By employing this framework, researchers can effectively qualify and quantify predictable workforce changes, generating valuable input data that can inform the arguments and conclusions of the study.

Our framework adopts an 8 point-based approach to systematically address the challenges of reorganising workforce task allocation. This approach entails initiating systematic reorganisation by targeting the following problematic areas: outdated skills, dynamic technologies, skills gaps, changing business models, loss of talent, aging workers and the need to mitigate risk (Academy to Innovate, 2024). As emphasised by Bruecker et al. (2015), effective workforce planning necessitates a methodical approach to redistributing tasks, commencing with problem definition and modelling, and then refining iteratively. The framework provides us with The Human Capital Institute (HCI) 8-point model which conforms to that recommendation as outlined below:

(i) *Articulate the business strategy*: Establishing the goals of digital transformation. Clearly defining the objectives of the digital transformation. Optimise workforce

dynamics, minimise costs, maximise logistical throughput through automation and other tech deployments.

(ii) *Segment roles:* Analysis and prioritisation of roles in order of mission critical. Identifying tasks by their priority, to support their allocation and scheduling based on workload distribution, availability, task dependencies, as well as their value add to the organisation.

(iii) *Conduct an environmental scan*: A Strategic Workplace Plan must consider both internal and external elements that can influence business trends. Identify, monitor and actively assess trends affecting the workforce and the organisation. Collecting and structuring internal and external data. External data would be about factors that may influence business trends and internal data about those that may influence workforce resources, task specifications, equipment capabilities, and operational constraints. Being able to parse this data out into some organisation, spreadsheets or databases.

(iv) *Analyse the current state*: Assess, inventory, and benchmark current workforce in terms of their skill sets, availability, and job requirements. Evaluating different allocation procedures for better utilisation of workforce and task assignments. Considering human centric factors like what each team member is best at, how much work they have on their plate, and you have a recipe for a predictive analytics process that takes people into account. Which means you cannot measure someone like you measure numbers.

(v) *Construct a detailed future*: Create a simulation of the organisation, its environment and the technologies 1-5 years ahead. Think about how the environment or technologies change. Iteratively adjusting their workforce structures based on the predictions generated by the predictive analytics and performance indicators that they have in place. Adjusting deployments of the workforce in response to changing market factors, logistical goals, and operational limits.

(vi) *Identify gaps*: Review the assessment and inventory in step 4 on current workforce vis-a-vis the simulated future state from Step 5. Testing out key performance indicators on these structures to determine effectiveness, i.e. lead time to ascertain what gaps exist between the two states and develop probable solutions.

(vii) *Create an action plan*: Make a plan-based on feedback and insight gained from the analysis Identify the gaps, to develop a plan to strengthen or reshape some or all of the organization's talent initiatives iteratively refining it to improve relevance and efficiency over time and set up benchmarks and KPIs.

(viii) Monitor and report: Track quantitative and qualitative benchmarks at specific milestones throughout the entire process. Distributing results

and suggestions to relevant teams or departments, to ensure they inform decision-making and contribute to continuous improvement.

This provides a strong theoretical framework for this study which allows this researcher to construct a more cohesive and nuanced understanding of the intricacies surrounding workforce shifts in the 5IR. "When applying this framework, a researcher can quantify and qualify inevitable shifts in the labour pool, yielding new and rich input data that can inform the findings and conclusions of their report.

CHAPTER THREE

METHODOLOGICAL CONSIDERATIONS

3.1 Introduction

This chapter begins by revisiting the research aim and its associated question, drawing upon the hypotheses and conceptual framework outlined in the literature review's conceptual model. Subsequently, it explains the philosophy, research design, description of the research site. The chapter further expounds upon the target population, sampling procedure, and the detail of data collection used the developed data collection tool. Following that, the chapter discusses how the data was processed and analysed. Finally, the section ends by discussing the limitations of the chosen research methodology.

3.2 Recapping of the Research Aims and Objectives

As discussed in section 1.4 the aim of this study is two-fold. To achieve the abovementioned aims, four research objectives were formulated. The first objective was to examine the key factors influencing modernisation initiatives in the South African gold mining sector.
The secondly, to assess how technology is deployment in South African gold mines and determine how it reshapes workforce. In addition, it important to determine which jobs are commensurate with the emerging standard operating procedures and establish the ways in which they will change organisational structures The final objective was to evaluate the strategies and frameworks for workforce planning and reorganisation in gold mines, assessing how they optimise task allocation and ensure both short-term adaptability and long-term talent sustainability. In view of this, the aims and objectives of the study informed the research philosophy which was utilised in this study.

3.3 Research Philosophy

Research philosophy includes different paradigms which represents the researcher's beliefs about reality, how knowledge is acquired and ethics in the research process (Saunders, et al., 2023) (Saunders, et al., 2023). These paradigms set out the philosophical and methodological

foundations on which to base research design and approach. Positivism is one familiar philosophical position that might be aligned with the methods of natural scientists. Positivism uses observable social realities to generate law-like generalisations (Crotty, 1998). This researcher continues that this method is based on objective and unbiased empirical data that is free of human interpretation. Tracing its origins to the anticipations of Francis Bacon, Auguste Comte, and the Vienna Circle of the early 20th century, he claims that positivism has evolved into various branches, up to twelve distinct varieties at least. The positivist tradition promises clear-cut and accurate knowledge, placing a premium on a scientific rigorous basis of enquiry. As he points out, however, constructivism is a paradigm shift away from the objectivism of positivism. Constructivism, this researcher explains, argues that truth and meaning are not related to an inherent quality in objects, but rather are created through human consciousness and lived experiences; whereas, objectivism , derived from the ancient Greek philosophers and refined through Scholastic realism and Enlightenment thought , asserts that knowledge should be objective and is capable of being comprehensively understood through the appropriate kind of inquiry. On the other hands, constructivism challenges this perspective by stressing the integration of human understanding and experience for a broader understanding of reality (Tashakkori and Teddlie., 2010).

Critical realism, the third perspective, lies between positivism and constructivism, a philosophical position that maintains that there is a real world out there, an "ontological" position, but recognises that this is one that cannot be wholly and objectively measured (Bougie and Sekaran, 2019). Observations, especially about abstract phenomena like motivation, culture or satisfaction, are always subject to interpretation. Critical realism highlights that we must explore and speculate on factors other than the classical visible events that have a multilayered genesis. According to Bhaskar (2011, quoted. in Tashakkori and Teddlie, 2010), to understand social phenomena, we must understand the structures which generate them. Critical realism often involves detailed historical accounts of social and organisational structures and their development and impact on everyday life (Reed, 2005). Deriving from this, you engage with epistemological relativism, which suggests that knowledge is defined in terms of its historical and social context, and social facts are constructed instead of existing independently (Bhaskar, 2008). This suggests that critical realist conceptions of causality cannot be reduced to statistical correlations and quantitative methods are acceptable (Reed 2005) quoted in (Tashakkori and Teddlie., 2010)

Critical realism challenges certainty offered by positivists, asserting that however much we try, research can only aspire toward an understanding of truth but never achieving it in an absolute sense (Bougie & Sekaran, 2019). Such perspective highlights not only the imperfection of data collection, but also the inherent biases of the researchers. Thus triangulation, i.e., the use of multiple methods, observations, and researchers, is critical to understanding phenomena more broadly. The critical realist's axiological stance recognises the impact of socio-cultural backgrounds and experiences on research. Hence, researchers following this philosophy attempt to neutralise prejudices and regulate neutrality while being aware of the inevitability of subjectivity in the knowledge creation process.

3.4 Research Design and Approach

A research design is the framework for collecting and analysing empirical data in a way that connects it back to the research questions and conclusions, providing a logical sequence of events in the methodology (Yin, 2014). The research design sought to provide greater clarity regarding the research problem, partly through a precise demonstration of the perspectives of knowledgeable individuals in the subject of this study, adopting a descriptive approach. A descriptive study is a method that aims to identify and clarify what is known, to describe events (Saunders and Lewis, 2018). According to Edgar and Manz, (2017) (Edgar & Manz, 2023)descriptive studies use tools such as case studies, interviews, and reports were the instruments used to collect and analyse data for research. In descriptive case studies, the questions tend to be the "how" and "why" questions that are similar to a case study, an experiment or a historical study. Mainly, this is because such questions deal with issues according to the compounds of operational elements observed over time and thus available via the detection of the occurrence or its dissemination beyond (Graue, 2015).

Descriptive studies have little to offer as far as explaining events but are well suited for relatively new or uncharted research areas (Punch, 2005). Based on aims and objectives of the study, the research was not limited to description but used explanatory research to primary answer the question of the research. The research frameworks were carefully chosen to highlight the relationships between variables clearly defined within constructs of each model. By wading into these theoretical relationships through testable hypotheses, the study sought to

not only identify what took place, but also to understand why and how these outcomes unfolded. Contrarily, because explanatory research finds the reason or reasons for an event to occur, it allows you to make predictions and to have a stronger basis for control over the future outcome. Therefore, explanatory knowledge or the explanation of events has more analytical powers than descriptives, i.e. state descriptive knowledge (Punch, 2005).

Owing to these two facets of the research, the study applied a descripto-explanatory approach, characterised by both descriptive analysis and explanatory theory testing. This integrated design enabled an accurate representation of expert views while digitally delving into the relationships between variables in the theoretical model. In addition, due to the interpretive nature of the research, an intimate understanding of the organisational contexts and activities was required, and not just data collection. This was accomplished through careful observation of appropriate ontological, epistemological, axiological and rhetorical considerations as prescribed by (Edgar and Manz, 2017)

Even though an inductive process could have proved useful in deriving insights for the South African context, the life cycle for theory on technology adoption was long enough for it to be justified to adopt a confirmatory research design for localised research. The research took a deductive approach, that aligned with its confirmatory aim of testing theories already established in the area of technology adoption with regards to South Africa. However, deductive reasoning starts with existing theories or frameworks, and researchers can develop hypotheses or propositions that will help them with data collection and analysis (Bryman, 2016) This was particularly appropriate for this study, where the literature review identified well established theory around technology adoption e.g., the Technology Map, Jacobs and Webber-Youngman 2017. Established Industry Framework – Strategic Workforce Planning (Academy to Innovate, 2024); Academy Specialized frameworks – Competency Model (Tepavicharova, et al., 2019) and Theory of Skill-Biased Technological Change Theory (SBTC) (Card and DiNardo, 2002) alongside Technology Acceptance Model (Davis, 1998). These and many others offer sound frameworks for understanding and measuring technology adoption, and its effects on employment.

Adopting a deductive approach meant that the research could systematically test theory against local data and confirm or reject their fit to the unique socio-economic and industrial landscape

in South Africa. Such an inductive approach may have led to new insights but as this study was confirmatory in nature, a deductive design was used to formally test the relevant research questions and the merit of existing theories. We used a deductive approach in a descriptor explanatory research setting, integrating descriptive and explanatory aspects. Descriptive research offered a rich description of practices surrounding technology adoption and workforce changes, as well as individuals and their organisation and explanatory research delved into the causal relationships between those variables. Such a dual approach allowed for a more nuanced understanding of the relationship between technology adoption and employment outcomes in South Africa. More information about the research design is presented in the subsequent sections, and the key components and structure of the research design are illustrated below

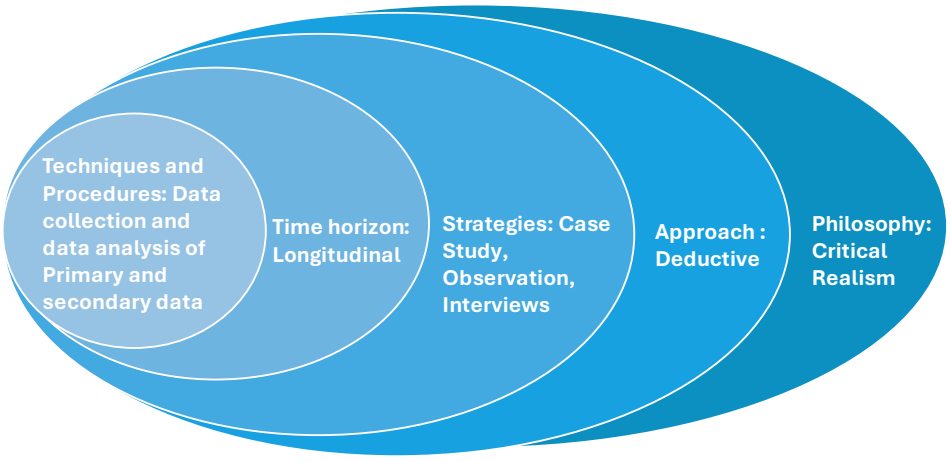


Figure 3.1: Adapted overview of the research design using the Research Onion.
Source: Adapted from Saunders, et al., (2023)

3.4.1 Unit of Analysis

This study aimed to investigate the perceptions of innovative technology adoption in the context of mine modernisation and its implications for work content, processes, tasks, environments, and employee skills requirements. The selected frameworks and models emphasised the transformative effects of technological advancements on workforce dynamics, particularly the integration of workforce planning and scheduling into production systems to establish intelligent workspaces. These intelligent workspaces are dynamic environments

where variables, such as skills demand and task efficiency, can be measured and analyse d over time.

A Multidimensional Analytical Model, informed by the overarching framework, was constructed around three key themes: technological adoption, skills requirements, and competency models. This model facilitated the development of grounded theory to explain how technology adoption has influenced the evolution of jobs since its inception and how it continues to do so. This theoretical foundation enabled the deconstruction of the research questions by addressing relationships between the variables under study. Furthermore, it provided a basis for testing whether the theories held true in their specific contexts and served as a lens for interpreting the results.

The unit of analysis for this study was technology adaptation, skills demand, the emergence of new and redundance of old jobs as well as human productivity over a 20-year period, reflecting the longitudinal impact of technological adoption in the mining sector. While this approach provided a structured basis for examining the research problem, its relevance extended beyond the immediate study, offering potential value to the broader research field.

This extended value was underscored by arguments from the European Centre for the Development of Vocational Training (2021), which highlighted the limitations of conventional methods, such as skill surveys and forecasting, in capturing emerging trends in technological change and skill needs. The increasing availability of big data and artificial intelligence methods has introduced new "real-time" tools for analysing trends and anticipating skill needs. Additionally, skill foresight techniques, which leverage in depth stakeholder insights about future technologies and competencies, are becoming increasingly prominent in addressing these challenges.

By adopting this framework, the study contributed to both the academic discourse and practical understanding of the intersection between technological adoption and workforce evolution in the mining sector. It provided a methodologically robust and contextually relevant basis for interpreting how innovative technologies reshape workforce requirements and labour dynamics over time.

3.4.2 Study population and sampling procedures

Since the research concentrates on employment components of the 5IR, which is a niche and developing area, the addition of stakeholders is essential for the building of the research. As aptly pointed out by Brent and Leedy, (1990), taking the time to select a relevant sample is crucial for collecting accurate and useful input data. In this regard, non-probability sampling techniques were implemented to choose the interviewees in the study. In this regard, the researcher used purposive sampling, which was later enhanced with snowball sampling. According to Desai and Potter, (2006) purposive sampling is a non-probability sampling procedure that is particularly useful for examining a specified field through the experiences of people who are informed, educated and knowledgeable. This technique is appropriate within qualitative and quantitative research approaches, as this makes it possible to intentionally select participants whose contributions are relevant according to the objectives of the research (Tongco, 2007). Although purposive sampling is by nature not impartial, he argues that this trait increases the technique's efficiency as it allows a researcher to concentrate on obtaining relevant and insightful data. In fact, she says, the strength of purposive sampling has been shown even when tested against random probability methods.

The data collected through purposive sampling is in part dependent on the experience and trustworthiness of the informants. As Tongco notes, the integrity of the sample has a direct impact on the study's results. So, one of the most important pieces of the research design is making sure participants are well informed and aligned with the goals of the study. The study designed its sampling to exploit the expertise of key stakeholders to develop in depth knowledge of the human capital aspects of the 5IR thereby enhancing the overall rigour and validity of the research findings. The researcher contacted the subjects via emails sent to the relevant employees of companies that met the criteria for inclusion. Then, snowball sampling was used, where a participant can refer the researcher to another who meets the criteria. This strategy aids the researcher in maximising the chance of reaching people who otherwise would have been excluded from taking part of the study (Saunders, et al., 2023). Snowball sampling is appropriate for studies that include in-depth interviews of a small, purposefully selected sample, Saunders, et al., (2023) continue. The researcher then asked the departmental heads, who oversee the digital transformation programmes at the mines, to recommend suitable participants. Participants were from different departments at the mines to ensure adequate

representation and included a mix of roles: HR practitioners, heads of engineering, trainers, and plant superintendents.

3.4.3 Data collection instruments

According to Creswell, (2009) data collection instruments must be selected appropriately corresponding to the research design and methodology. He emphasises that careful planning of these instruments adds to the credibility and relevance of the data being collected while also addressing the research problem effectively. Creswell also emphasises the importance of an extensive literature review in the early stages of the study to ground the research within the existing literature. According to Kothari (1990), he differentiates between research technique and research instruments. He asserts that research technique is defined as the overall strategy you choose to integrate the different components of the study in a coherent and logical way, thereby, ensuring you will effectively address the research problem. On the other hand, he explains that research instrument refers to the techniques that the researchers will implement; and it includes questionnaires, interview guide, observation checklist, etc. The differences between a method, technique, and instrument/tool for data collection are well-described by Creswell (2009) and Kothari (1990), as illustrated in the Table 3.1.

Table 3.1: Comparison of Methods, Research Techniques, and instruments

	Comparison of Research Methods, Research Techniques, and Data Collection Instruments		
Type	**Methods**	**Techniques**	**Data Collection Instrument**
Library Research	Analysis of historical records	Recording of notes, Content analysis, Tape and Film listening and analysis.	Notes, content analysis tools, tape recorders
	Analysis of documents	Statistical compilations and manipulations, reference and abstract guides, contents analysis.	Statistical software, reference materials, abstract guides
Field Research	Non-participant direct observation	Observational behavioural scales, use of score cards, etc.	Behavioural scales, score cards
	Participant observation	Interactional recording, possible use of tape recorders, photographic techniques.	Tape recorders, cameras, interaction logs
	Mass observation	Recording mass behaviour, interview using independent observers in public places.	Observation tools, interview guides
	Mail questionnaire	Identification of social and economic background of respondents.	Questionnaires, demographic forms
	Opinionnaire	Use of attitude scales, projective techniques, use of sociometric scales.	Attitude scales, projective tools, sociometric scales
	Personal interview	Interviewer uses a detailed schedule with open and closed questions.	Interview schedules
	Focused interview	Interviewer focuses attention upon a given experience and its effects.	Interview guides
	Group interview	Small groups of respondents are interviewed simultaneously.	Group interview guides
	Telephone survey	Used as a survey technique for information and discerning opinion; may also be used as a follow-up.	Survey forms, telephone devices
Laboratory Research	Small group study of random behaviour, play, and role analysis	Use of audio-visual recording devices, use of observers, etc.	Audio-visual devices, observer logs

Source: Compiled from Creswell 2009; Kothari (1990),

For the purposes of this study, the data collection process was iterative, as early insights explored and informed the research design throughout the study. The study incorporated a combination of primary and secondary data sources to provide a comprehensive understanding of the phenomenon under investigation, a process in accordance with Creswell's (2014) recommendations. Semi-structured interviews were conducted with expertise in the South African gold sector, targeting a large-scale underground gold mine located in the Witwatersrand. This first-hand account from industry practitioners provided a rich understanding of the main themes and challenges for mine modernisation. Also, secondary materials including, but not limited, to company reports, relevant literature, etc, were used to develop a case study, which formed context and background. As Saunders et al. (2023) state, primary data and case study represent complementary strategies in enriching rather than mutually exclusive elements of the research process.

This informed the iterative process of collecting data, starting with mine visits as part of an observational technique to see time-sensitive details of operational settings, human capital, and technology. Such visits provided the researcher the context and revealed patterns and themes that needed deeper study. A case study was developed simultaneously, based on secondary data, which provided extensive context for our observations and anchored the study with theoretical and industry practice. Based on these first steps, semi structured interviews were then established and carried out. The interviews were intentionally designed to explore findings from the observational visits and case study in greater detail. In this study, the data collection instruments; observation, case study, and interviews were integrated to ground the study in both the theoretical and practical perspectives of modernisation initiatives in South African gold mines.

Kawulich (2006) underscores those qualitative methods of data collection, including interviewing, observation, and document analysis, fall under the umbrella of ethnographic methods. These approaches, when applied iteratively and cohesively as demonstrated in this study, offer a robust framework for understanding complex socio-economic and organisational phenomena. This multi-method approach ensured that data was not only credible but also deeply contextualised, enhancing the validity and reliability of the research findings.

(i) Observation

Observation has been described as the "systematic description of events, behaviours, and artifacts in the social setting you choose to study" (Marshall and Rossman, 1989; as cited in Ciesielska et al., 2018). While Saunders et al. (2023) highlight that observation is somewhat underused in research, they stress that the method can be rewarding and illuminating, adding great depth to the research data. Ciesielska et al. (2018) take this a step further, claiming that observation is one of the most fundamental modes of doing social science, although its implementation is a complex task. For research questions and objectives around what people are doing, observation is the most natural route to discover this fact (Saunders et al., 2023).

Types of observational method are many and varied and can involve different methods and approaches and can be used in various ways, including participant observation, and nonparticipant observation (Ciesielska, et al., 2018). In conducting this study, the researcher utilized a method for the research that consisted of participant observation. According to

Kawulich (2006), participant observation is a process as researchers learn about the activities which people engage in while they are in the field through participating in and observing these activities. This method provides context for establishing sampling recommendations and interview protocols, which should be considered a foundational step for subsequent qualitative research.

Participant observation is one of a distinctive set of research methods that has become a foundational part of anthropological fieldwork. Ciesielska et al. (2018) argue that this approach is specifically beneficial in studies that involve "active looking, enhancing memory, informal interviewing, and writing detailed field notes" as part of a fieldwork continuum. As Saunders et al. (2023) point out, participant observation can be the main method in a research project or one of multiple complementary qualitative methods. In this research, the researcher used it for the latter, knowing that it does abstract a part of being used as a single approach. Kothari (1990) summarises these constraints, such as interpretation is a subjective process and the possibility of over estimation by the researchers about the phenomenon observed. Kothari (1990) makes the distinction between controlled and uncontrolled observation. Controlled observation is governed by specific plans, often heavily influenced by experimental procedures, while uncontrolled observation occurs in the natural world, without controlled procedures or precision instruments, and is intended to provide a spontaneous and holistic view of life and behaviour. The latter is useful when tom prove the naturalness and completeness of behaviour, as there is enough time to get an observation in their natural environment.
For the data set collected in this stage of the research, a preliminary inquiry to define the notion of technology adoption in the case of gold mining operations was executed. Instead of being the primary research question, this preliminary study enabled the researcher to create a baseline knowledge of the phenomenon being studied. In order to build foundational knowledge that would guide further phases of the research, the researcher asked, "What specific dimensions and characteristics define the technology adoption process in this context. As this was a first step exploratory study, observation was considered a key first step in a wider multi-method data collection.

All of which led the researcher to formulate three main goals for this stage of the research. The former was to set the stage for the prevalence of technology adoption across the gold mining business. This was followed by the race to prove the prevalence of technology adoption understand the potential impact of such technologies in workplace dynamics. The third goal

was to assess the strategies and frameworks for workforce planning and reorganisation of gold mines, as well as the optimised allocation of duties and the immediate adaptability and sustainable talent generation resulting from this interaction. Due to the researcher not having had access to the practical environment of smart mining operations initially, participant observation was deemed an adequate and essential method. This enabled deep interaction with the context and reveals meanings attached to participants' actions and experiences with technology adoption (Saunders et al., 2023). The mine visits, which the researcher conducted as part of an observational exercise, were preliminary, occurring before the pilot interviews. These initial observations were vital for informing the second stage of the research, semi structured interviews.

(ii) Case Study

The case study is an extensive research method designed for the in-depth examination of a specific situation, event, or context, often within real-life settings (Yin, 2003). Unlike broader methodologies that emphasise general trends, the case study approach delves deeply into a defined subject, making it particularly valuable for investigating complex social, organisational, or environmental phenomena.

Indeed, Yin (2003) emphasises that case studies are appropriate when the research involves "how" and "why" type questions and when the number of relevant variables is much larger than the number of data points. This approach requires data collection from a variety of evidence sources, including, for example, interviews, documents, archival records, direct observations and physical artefacts. Triangulation synthesises these varied data sets and informs their depth and reliability (Yin, 2003). Theoretical assumptions drive this process of gathering and analysing data, as well as its relevance and rigour within the study.

Research involves definite cases that contain more independent variables than the number of data points (Yin, 2003) As a result, data should come from multiple sources, and data obtained are triangle combines in several separate points. This process is done by having pre-defined theoretical assumptions that describe your data collection and analysis process

Patton & Appelbaum, (2003) argue that it is vital that the case study is conducted in accordance with a structured and standardised procedure, which will ensure that the results from case study research are legitimate, credible and valuable. High-quality case study research is rigorous; by

following systematic process, using multiple data-sources, 'contextualising the analysis' and providing transparency, the rigour necessary is possible. Upon deciding that the case study would be the right course of action, a few main steps must now follow; Phase 1 will concern the research design, i.e. the objectives to reach, the case(s) selected as well as the theory to guide the case study. Second, data collection that combines information from various sources, including interviews, documents, and observations to create an extensive evidence base. Then comes data analysis where synthesising and interpreting the collected data through systematic techniques including triangulation to extract patterns and insights is performed. Finally, we articulate the results in a way that answers the research questions and links back to the theoretical framework.

Yin (2003) distinguishes four basic case study designs, organised along two dimensions. The first dimension distinguishes single-case versus multiple-case design. Single-case studies offer in-depth understanding of one context whilst multiple-case studies allow for broader cross case comparisons and more robust generalisations. A second dimension differentiates holistic from embedded designs. Holistic designs study a single unit of analysis e.g. the intervention being implemented in one site), while embedded designs study multiple units within a single case e.g. the intervention implemented across the multiple sites within the same institution). The various dimensions can be used separately or together according to the goals of the research and the complexity of the phenomenon of interest.

According to Paton and Appelbaum (2003), case studies serve as a critical avenue of research in organisational science, particularly for theory generation and contextual exploration. As (Hoffman & Novak, 1996) Hoffman and Novak (1996) contend, reviewing secondary data not only anchors research within existing knowledge but also offers necessary context to support the study's relevance. This study employed a holistic single case study design to examine the process and impact of mine modernisation, specifically focusing on human centric technological transitions in a large-scale underground gold mining operation in South Africa. The mine remains unnamed due to ethical agreements and is referred to here as *"the mine under study."*

The following secondary data sources were collected and analysed:

(i) Integrated Annual Reports (2018–2023)

(ii) The mine's Social and Labour Plan (SLP) (2018–2022)

(iii) Internal presentations on technology adoption strategies

(iv) Organisational structure and workforce composition documentation

(v) Digital infrastructure development plans (e.g., LTE deployment, control room schematics)

(vi) Public communications and industry journals

(vii) Site visit reports by the researcher

The process for accessing this data included formal approval from the mine's executive team, supplemented by secondary access to public repositories, government databases, and professional mining association archives. This data informed the mining cycle analysis used to monitor human and technological interactions across the underground production value chain. The case study methodology was chosen because it aligns with the objective of offering a detailed, contextualised account of how modernisation affects employment structures, operational efficiency, and skill transitions in the South African gold mining industry (Yin, 2003; Desai & Potter, 2006). (Yin, 2003)

Summary Table: Research Objectives and Corresponding Methods

Objective	Corresponding Method	Explanation
1. To examine the objectives and drivers of mine modernisation	Case study (Annual Reports, SLP), Interviews	Reviewed corporate documents and explored leadership views in interviews
2. To analyse the strategy for technology adoption and integration	Case study (tech plans), Interviews with engineering heads	Analysed LTE plans, control systems and insights from technical management
3. To evaluate the implications of modernisation on the workforce structure	Case study (HR data from SLPs), Interviews	Analysed workforce transition documents and HR/training department perspectives
4. To assess emerging skill gaps and workforce planning	Interviews (Training Dept, HR), Secondary data from SLP	Data informed by internal training agendas and future workforce planning
5. To explore perceptions and experiences of employees	Interviews using semi-structured schedule	Thematic coding of lived experiences using 7 targeted interview themes

Source: Researcher's own construction

(iii) Interviews

Interviews are defined as systematic conversations between two or more persons and take place with an intentional, focused agenda of exchanging information (Kahn and Cannell, 1957). According to Creswell (2009), successful research by interview begins with both an awareness of what is known/or not known. Reading the relevant literature and prior data is a baseline for primary research design, as well as a comparison with later results (Novak, 1996). In explanatory research, interviews can help in understanding the relationship between variable(s) identified in descriptive research, such as case studies (Saunders et al., 2023) . Standardisation, flexibility, and depth of data considered are the differences between the three main types of interviews structured, semi structured and unstructured.

Structured interviews are conducted using a very standardised method, the same predetermined questions are answered, both of which are measurable. Commonly known as interviewer administered questionnaires, they emphasise standardisation and bias mitigation, which is common to quantitative research techniques (Saunders et al., 2023)). Semi-Structured interviews are flexible but guided by themes and important questions, which can be modified or extended as the process of interaction occurs (Creswell, 2009). In qualitative research, semi structured interviews are a commonly used approach for generating rich, context specific knowledge. Questions during the conversation may evolve to explore emergent themes, and audio recordings and detailed notes are often relied upon in data collection to preserve authenticity. Unstructured Interviews are conducted in an exploratory format, where participants drive the conversation according to their own views and stories. This format is particularly effective when investigating broad (or possibly complex) topics in detail, using an informant (or respondent) approach (Easterby-Smith, et al., 2002)

Interviews may be done face to face, over the telephone or online, or in group settings, like focus groups, to consider what is common among those experiences. Type of interviews will depend on the research objectives, type of information needed, and practicalities such as availability of resources and time (Saunders, et al., 2023). Semi structured interviews were chosen for this study, as they allow flexibility to adapt questions to explore areas unanticipated but significant (Kvale, 1996). And its capacity to delves into complex, nuanced phenomena (Kvale, 1996). This format lends itself especially well to discerning participants' insights and experiences (Desai and Potter, 2006). Respondents may also elaborate on their experiences

yielding rich qualitative data (Desai and Potter, 2006). Moreover, it supports the establish rapport and comfort level, both of which were useful in these participants responding authentically (Kvale, 1996).

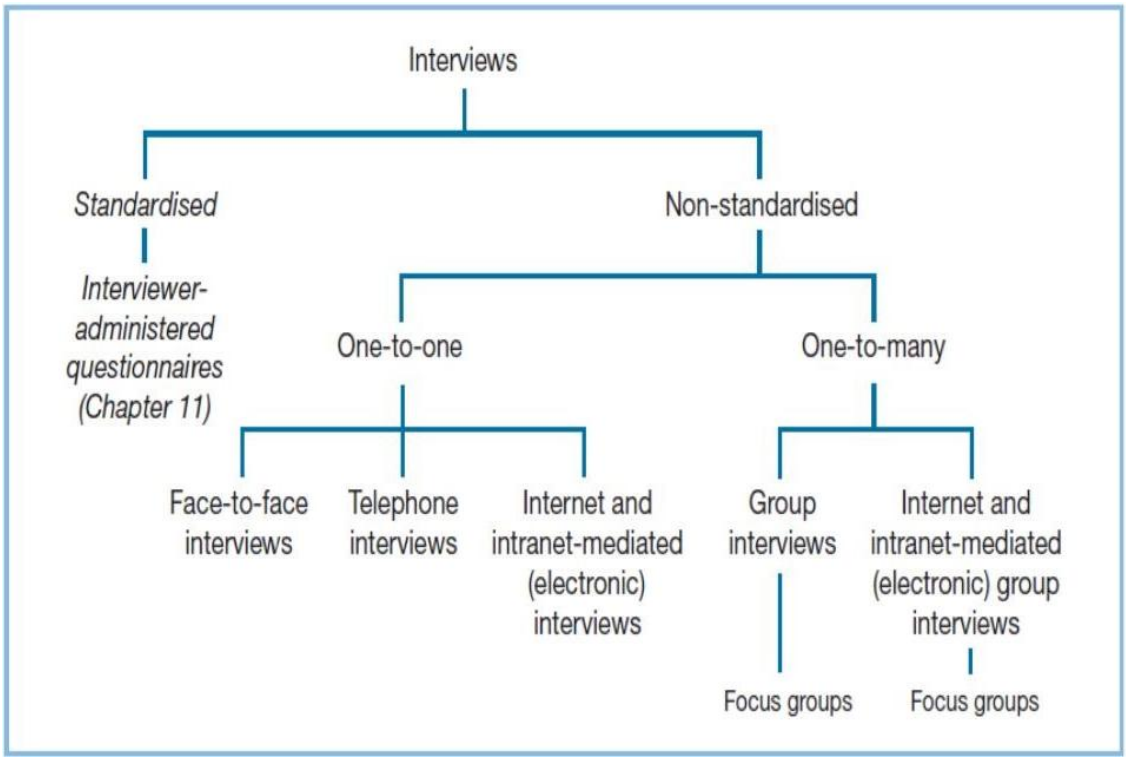


Figure 3.2: Forms of interviews
Source: Saunders, et al., (2023)

There is no denying that the semi structured nature of the interviews can yield great results. However, much depends on the design of the interview schedule, which is a key component in successfully performing semi-structured interviews. A poorly designed schedule may lead to respondents suffering from fatigue and disengagement, thus threatening the quality of the data produced from such processes (Desai and Potter, 2006). To that end, effective interview schedules should balance length and depth to prevent overwhelming participants while still managing to elicit meaningful insights. They should also utilise clear, relevant, and unambiguous questions aligned with the study's objectives. Lastly, there must be a pilot test to work on a structure and test the data validity and reliability at this stage. Based on these principles, we limited the interviews of this study to a maximum of one hour per session to have at least one of the typical interview techniques, not just because of participant engagement but general result richness as well while upholding the most tasteful academic integrity.

Interviews were used to supplement the case study by capturing rich, nuanced insights from key personnel. Following Kvale (1996) and Creswell (2009), semi-structured interviews were employed to allow a guided yet flexible exploration of the research themes. A total of seven participants were interviewed: two from Human Resources, two from the Training Department, one Head of Engineering, two Operational Managers (drawn via snowballing from initial participants). Participants were selected using two sampling methods, the first was Purposive Sampling, key informants with strategic oversight (e.g., engineering head, HR lead). The second was Snowball Sampling, participants recommended additional individuals with relevant insights (e.g., operational managers). The sample size was determined by the availability of participants granted through the mine's internal permissions process and the need for information-rich cases to meet the qualitative depth expected in this kind of study (Saunders et al., 2023).

To ensure data quality, an interview schedule was pilot tested with two participants (Heads of Engineering and Training). This led to refinement in phrasing, ordering, and depth to maintain engagement and mitigate fatigue, in line with Desai and Potter's (2006) recommendations on balancing interview length and depth. Each interview lasted approximately one hour and was conducted via video call or in-person, depending on availability. Audio recordings were made (with consent) and transcribed verbatim, in line with Bryman (2016), to preserve accuracy, emotional inflections, and non-verbal cues (Pontin, 2000). Consequently, in this study, scheduled interviews were centred on the themes of interest presented in table 3.2

Table 3.2: Interview themes

Interview themes
Key objectives and triggers of the mine's modernisation initiative
Technology implementation strategy
Workforce structure
Identifying and addressing skill gaps
Planning and reorganising the workforce
Impact Assessment of technologies
Change management
Diversity and inclusion
Developing talent pipelines
Future outlook
Human-centric technology adoption
Emerging technologies perception

Source: Researcher's own construction

3.5 Data Analysis

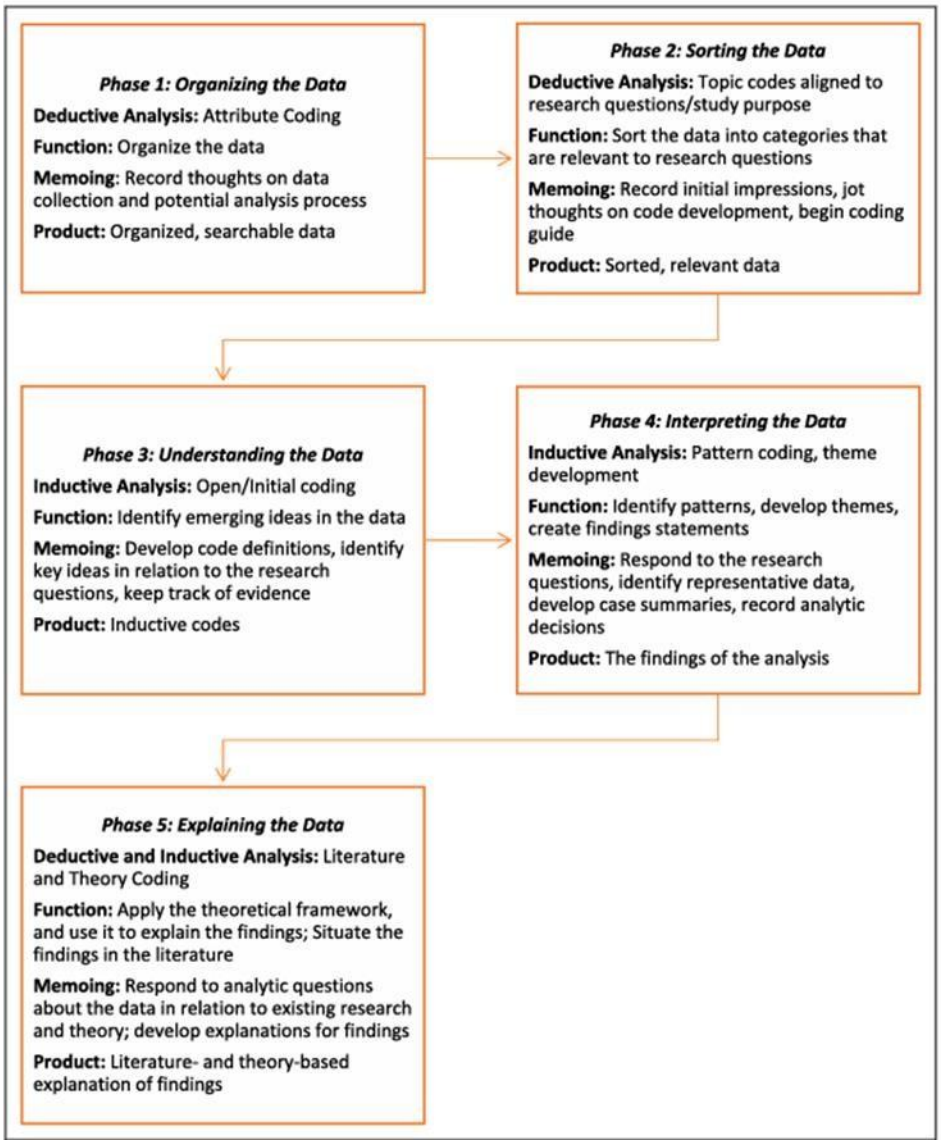


Figure 3.3: The five phase process of data analysis
Source: Bingham, (2023)

Data analysis is a process to gather, model, and transform data to highlight useful information, draw conclusions and support strategic decision making (Güler, 2016). The process uses a system of recurring steps to turn raw data into useful dashboards, which can then be used to help you make a decision or develop a theory. In the same stream, Tumele (2015) states that data analysis is aimed at reviewing, grouping, cross-tabulating, testing, or recombining evidence to find patterns, build explanations, create time-series analyses, and formulate theories. Bingham (2023) proposes a Five-Phase Qualitative Analysis Process to ensure the

planning, articulation, and execution of systematic and transparent data analysis. An audit trail alongside this approach improves the reliability and credibility of qualitative research. In brief, the process consists of data organisation, sorting data based on topic; data open/initial coding; the findings development; the findings discussing.

For the first phase, (Kothari, (1990), recommends that the data be organised categorically. Accordingly, the researcher organised her data categorically. For data collected from observations, she compiled field notes of her observations, highlighting practical technologies, training methods, technology acceptance and acclimatisation of the workers at different levels of operations and other key aspects. For semi structured interviews, she ensured that each transcript is clean and ready for analysis. For published documents, she organised these by theme, topic, or relevance, extracting relevant sections or quotes for analysis. The researcher spent time reading through all the data and identifying emerging patterns, themes, and concepts, thereby getting to develop a deep understanding of the dataset. For the second phase which is about sorting data into relevant topical categories, the researcher used Microsoft Word to create a codebook tag using a priori codes representing a list of categories derived from the data in line with the research questions. Examples of themes are technology adoption, training methods, workforce impact, challenges, benefits, etc. Examples of sub-themes include specific technologies, skill development processes, displaced skills, emerging skills. She followed this with developing a coding framework. Coding refers to the process of assigning symbols or numbers to responses to classify them into limited, mutually exclusive, and exhaustive categories relevant to the research problem. Each category must represent only one concept (Kothari, 1990). As guided by (Bingham, 2023), the researcher developed inductive codes based on patterns observed in the data, whereas for deductive codes she used pre-existing frameworks and literature to guide the coding. Coding was carried out utilising the Microsoft Excel spreadsheet package to develop attribute codes that identify data type, source and period, then tags the data associated with each of these attribute codes to categorise and manage the data. For phase 3, which is Open/Initial Coding, the researcher read through the data in each category, creating, defining, and applying codes as she read. From that she then used manual methods in Excel for qualitative data analysis the researcher assigned codes to segments of the data. For observations, code sections where workforce evolution, education and training trends, training impact, job transformation, and 5IR-driven changes are mentioned. For interviews, code based on the themes mention in Table 3.2. For published documents, focus on coding

relevant sections that align with the research focus. This phase is where researchers drew on the process of comparing how technologies influence different aspects of employment between observation data and interview data while identify gaps or consistencies between published documents and interviews. (Bingham, 2023) recommends that researchers create a memo that includes each of the research questions to have a running log of possible answers to the research questions, potential evidence from field notes and interviews, and supporting quotes. Accordingly, the researcher created a Microsoft Word document for this purpose. Phase 4 and 5 of (Bingham, 2023)'s process involves developing the findings of the analysis and discussing the findings. These form part of the chapters to follow.

3.5.1 Methods for Workforce Evolution Analysis

The workforce evolution model was developed using principles from Strategic Workforce Planning Framework and quantitative forecasting techniques to analyse the impact of modernisation at the mine from 2017 to 2037. The equations used in this analysis applied in order to get to the following outcomes:

(i) Using a logarithmic decay function, the gradual reduction of jobs made redundant due to automation and digital transformation was estimated in order to compute phase out obsolete roles.

(ii) A sigmoidal growth function modelled the adoption rate of new technological roles as digital infrastructure matured, allowing for a way to introduce emerging roles.

(iii) A Markov transition model was applied to estimate workforce movements between obsolete, transitioning, and emerging job categories, incorporating upskilling efforts and giving us the skill transition and training impact.

(iv) By integrating data from the mine's customised workplace skills programme (WSP Hard to Fill Vacancies and Critical Skills Projection), regression-based extrapolation to estimate the demand for critical roles based on historical vacancy rates was used.

(v) Weighted adjustments were applied to reflect employment equity targets, training interventions, and external market factors, providing for employment equity and sustainability considerations

These formulae allow for customised workforce planning in mining modernisation while considering the balance between automation and human capital development.

Methodology for Workforce Evolution Analysis

The workforce transformation was analysed using:

(i) *Historical Data (2017 - 2018):* Used as the baseline for workforce composition.

(ii) *Extrapolation and Trend Analysis (2019 - 2037):* Used mathematical models to estimate future workforce trends based on training programmes, automation adoption, and new role emergence.

Key Variables Used in Computations

- *Wt* = Workforce size in year *t*
- *Ot* = Number of obsolete jobs in year *t* due to automation or industry decline
- *Tt* = Number of transformed jobs in year *t* due to upskilling or reskilling programmes
- *Et* = Number of emerging jobs in year *t* due to new technologies
- *Rt* = Recruitment rate for critical and core skill positions
- *At* = Attrition rate (retirements, resignations, industry exits)

Equations Used for Workforce Projections

Obsolete Jobs Over Time

Obsolete jobs were calculated using an exponential decay model:

Ot = Ot -1×(1- d)Ot = O_{t-1} \times (1 - d) where:

- *d* = Decline rate of obsolete jobs (estimated from industry trends, typically 5%-15% per year depending on automation speed).

Transformed Jobs Due to Upskilling

Transformed jobs were estimated based on the number of workers trained annually: Tt=∑i=1n(Li,t+Bi,t/Fi) Tt=\sum_{i=1}^{n}\left (\frac{L_{i,t}+B_{i,t}}{F_i}\right) where:

- *L_{i,t}* = Number of learners enrolled in programme *i* at time *t*
- *B_{i,t}* = Number of bursary recipients in programme *i* at time *t*
- *Fi* = Failure/dropout rate in programme *i*

This equation ensures that we only count successful learners and bursary recipients who transition into skilled workers.

Emerging Jobs Over Time

Emerging jobs were projected using a technology adoption growth function: $E_t = E_{t-1} + \alpha \times (1 - e^{-\beta t})$ *Et*=E_{t-1}+\alpha\times (1-e^{-\betat}) where:

- *alpha* = Maximum expected number of new jobs created (based on industry forecasts).
- *beta* = Rate of adoption of new technology-driven roles (determined from digital transformation trends).

This equation follows an *S-curve adoption model*, meaning that new job creation starts slow, accelerates, and then stabilises as technology reaches full adoption.

Overall Workforce Evolution

Total workforce at any time *t* is calculated as: $W_t = W_{t-1} - O_t + T_t + E_t + R_t - A_t$ *Wt* =Wt-1- *Ot* + *Tt* + *Et* + *Rt* - *At* *Wt* = W_{t-1} - Ot + *Tt* + *Et* + *Rt* - *At* where:

- *Wt* = Total workforce at time *t*
- *Ot* = Jobs becoming obsolete
- *Tt* = Jobs being transformed
- *Et* = Emerging job roles
- *Rt* = New hires (based on recruitment needs)
- *At* = Attrition rate (employees leaving the workforce)

This ensures that all workforce changes are accounted for dynamically over time.

Application to Mine Workforce Data (2017 - 2037) Using the equations above, the following steps were taken: *i.* Extracted 2018 workforce data as a baseline. *ii.* Classified jobs into obsolete, transformed, and emerging based on training programmes, automation, and industry trends. *iii.* Applied the exponential decay formula to estimate how many jobs would become

obsolete over time. *iv.* Used training data and learnerships to calculate how many positions could be retained through upskilling.

v. Modelled the emergence of new digital jobs using the S-curve growth function for technology adoption. *vi.* Incorporated hiring and attrition trends based on historical recruitment and retirement patterns.

vii. Generated a workforce projection heatmap to visualise workforce shifts from 2017 to 2037.

3.6 Methodological Reflections

This study was conducted as part of a broader research programmes designed to address the implications of modernisation on employment within the mining sector, focusing specifically on job creation, displacement, and evolving skill requirements. The ultimate aim of the programmes was to develop a comprehensive framework for a modern workforce tailored to the needs of technologically advanced mining operations. The researcher's involvement was predicated on a successful proposal submission, with the programme being financially supported by a consortium of public and private sector stakeholders interested in people, technology, mining, and research.

Even with such an advantageous overlap between the proposed research agenda and the information needs of the mining sector, it proved to be fraught with difficulties for the researcher when it came to the actual data collection. Several mines, some of which funded the above mentioned programme, were hesitant to participate in the study due to the sensitivity around this topic. In particular, this was true amongst companies heading towards or recently having recently been through retrenchment processes on the back of modernisation efforts. This push back sharply limited the qualitative data collection scope, leading to a narrow pipeline of sample size and an extended timeline of research completion.

In order to overcome these obstacles, the researcher focused on secondary data sources, such as publicly available reports, industry journals, and annual integrated reports. Thus, a case study methodology was used for the main study design with a combination of semi-structured interviews and observational data as subsidiary instruments. Through this methodological triangulation, the research managed to retain its depth and robustness despite restrictions on direct access to participants.

As it outlined in Section 3.1- Research design and approach, the steps taken in the research methodology The researcher initiated a preliminary phase working toward establishing a clear understanding of the definition of technology adoption in the context of gold mining before addressing participants at the gold mine where semi structured interviews would finally take place. Part of this phase consisted of two site visits to the mine, which functioned as an exploratory exercise aimed at exposing the researcher to operational processes, technological development, and workforce dynamics. Insights drawn from these visits were telling as they brought out important factors like training programmes for underground production workforce, the role of surface control centres as the nerve centre for connection to the mine and the interaction between OEMs and mine operators. This phase informed subsequent diagnostic and purposive sampling strategies through informal discussions and observational notes.

Following the exploratory phase, the study moved on to the interview phase, which had to comply with strict ethical guidelines imposed by the University. Permits were obtained from the mine, but this had been a slow and administratively difficult process. Only one mine, out of the six approached, granted the required approvals, with some citing confidentiality concerns or ignoring requests in others. After gaining approval, the researcher created participant information sheets and interview schedules in English, the language of choice amongst all the participants. The mine sample included seven Key Interview Respondents (KIR) from the mine. These comprised human resources department (KIR1, KIR2), the training department (KIR3, KIR4), and the head of the engineering department (KIR5), along with two operational mangers involved in strategic digital transformation and workforce planning (KIR6, KIR7).

Interviews at the mine followed a mixed approach: standardised questionnaires supplemented by interactive one on one electronic interviews to accommodate participants' time constraints and allow for more reflective responses. This phase, while arduous, provided rich qualitative data and allowed the researcher to delve into nuanced perspectives on the socio-technical transformations occurring within the mines. Simultaneously, the researcher devoted considerable effort to constructing a comprehensive case study. This approach leveraged publicly available data to contextualise findings from the interviews and provide an integrated understanding of the sector's transformation. The combination of interviews and case study analysis proved invaluable in achieving the depth required for this in-depth examination of the changes and challenges facing the mining workforce.

These different phases of engagement helped gain not just critical empirical insights but realised deep reflections on the human aspect of modernisation. The implication that mining companies cannot protect all current jobs in the face of technological advancement drove even greater academic interest in equitable and sustainable transitions in the workforce. This research, thus, highlights the multifaceted relationship between technological advancement, industry workforce reorganisation and industry ethical responsibility.

CHAPTER FOUR

EMPIRICAL EVIDENCE

4.1 Introduction

This chapter is dedicated to presenting the findings of this study which were obtained from the data collection phase., guided by the research questions outlined in Section 1.3. These questions not only shaped the data collection process but also served as the foundation for the subsequent discussions. Data were collected through semi-structured interviews and document analysis, and the results are presented thematically under each objective. Emphasis is placed on the insights from key interview participants (KIPs), triangulated with strategic documents where applicable. Quotes have been streamlined to those that directly contribute to the objectives of the study.

4.2 Perceptions on the Primary Factors Influencing the Modernisation Initiatives in South African Gold Mines

This section addresses Research Question one by examining how policy frameworks, economic pressures, and labour dynamics shape modernisation strategies in gold mining. This subsection delves into the empirical findings from the case study mine, drawing on data from annual reports from, field observations and interviews conducted. It provides a detailed narrative of the mine's modernisation trajectory, supported by concrete examples and strategic documentation

4.2.1 Case Study Insights into modernisation drivers at a South African gold mine

The section outlines the six main drivers of modernisation at the mine under study. The researcher's observations of the mine's modernisation journey from 2017 to 2024 reveal the profound foundation of its technological integration strategy and the accompanying effects on workforce dynamics, safety, and productivity. Based on the 2017 company integrated annual report, the modernisation process, which was part of the Innovation and Technology strategy, was approved by the board in late 2016. According to the 2018 annual report, the mine first articulated its vision in 2017 in response to industry-wide challenges, including declining productivity, rising operational costs, and safety concerns. The goal was to transition into a "Mine of the Future" by integrating advanced technologies and sustainability principles. The

company's modernisation agenda is driven by a three-pillar strategy, which aims to create enduring value beyond mining:

Strategic Pillar 1: Maximise potential from current assets through people and innovation

Strategic Pillar 2: Build on their leading commitment to ESG Sustainability

Strategic Pillar 3: Grow the value and quality of their portfolio of assets

This would then require establishing the foundational elements of the "Mine of the Future" across operations, which were articulated by the following objectives:

(i) *Health and Safety Imperatives*: The annual reports from 2017–2021 reveal that traditional mining methods posed severe health and safety risks, with high injury rates underscoring the urgent need for improved safety measures. The modernisation vision was, therefore, partly driven by the necessity to reduce workplace hazards through mechanisation, automation, and advanced monitoring systems. The deployment of Collision Avoidance Level 9 (CAS Level 9) systems is a key intervention in this respect. As KIR7 noted, the mine is "leveraging technology to achieve the highest safety standards," which directly aligns with Department of Mineral Resources and Energy (DMRE) compliance efforts. Gaps in prior implementations have further necessitated integrating safety technologies proactively into operational planning to protect lives and meet regulatory expectations.

(*ii) Escalating Production Costs and the Drive for Efficiency*: Old machinery and legacy mining methods were deemed inefficient, and rising production costs threatened the mine's financial viability. The economic pressure, according to annual reports and interview respondents, accelerated the drive toward automation, mechanisation, and process optimisation. KIR7 reinforced this view, stating the mine is focused on "increased productivity through automation, integrated systems, and tele-remote operations" while simultaneously "reducing energy, labour, and equipment maintenance costs through advanced digital solutions." These insights validate the strategic necessity for digital transformation to ensure cost-effective production and operational resilience.

(*iii) Digital Transformation and Variability Reduction*: The mine initially faced significant challenges due to fragmented and spatially disconnected technical data. Without real-time integration, version control was compromised, limiting the mine’s capacity to optimise production. In response, a formalised data consolidation process was implemented, enabling

the integration of operational and financial systems. The creation of an Operations Control Centre and underground network upgrades were pivotal for real-time data monitoring and decision-making. Echoing this, KIR7 described "building an Operations Control Centre and upgrading underground networks to enable seamless data collection, monitoring, and decision-making" as a cornerstone of digital modernisation. By 2024, the incorporation of AI and predictive analytics enabled smarter planning and variability reduction, resulting in enhanced performance and competitiveness.

(iv) Resilience and Competitiveness: As highlighted in the 2018 and 2019 annual reports, the mine has faced ongoing volatility due to economic cycles, evolving regulations, and technological disruption. To remain sustainable, it has adopted digitalisation and sustainability-driven practices. KIR7 emphasised "future-proofing operations" and demonstrating stakeholder value through efficiency, safety, and environmental responsibility. The modernisation programme has thus reinforced economic and technological resilience by reducing dependence on outdated techniques, boosting sustainability metrics, and aligning with evolving industry benchmarks.

(v) Stakeholder Value Creation: Despite substantial capital injections post-acquisition in 2006, the mine struggled to yield consistent profits. Chronic underperformance and missed targets eroded investor confidence, while surrounding communities and employees increasingly demanded accountability. As a result, stakeholder pressure became a vital trigger for modernisation. KIR7 affirmed that modernisation is also about “demonstrating value to stakeholders,” which is reflected in improved transparency, ESG compliance, and engagement practices.

(*vi) Workforce Transformation and Human Capital Development*: The 2018 annual report and interview data converge on the critical role of workforce transformation. Labour concerns about job losses and role changes initially fuelled resistance to modernisation. KIR7 described how the mine implemented “immersive training, VR simulations, and exposure to new technologies” to prepare workers for the future. Change management strategies were key to shifting workforce mindsets and easing cultural transition. Skills development is no longer ancillary; it is central to the mine's modernisation model. Cross-functional collaboration and integrated operational systems are now part of a redefined labour environment.

(*vii) Current Strategic Focus Areas – Survival Before Growth*: Interview data from KIP6 reveals that while growth-oriented technologies are acknowledged, the mine's immediate modernisation focus remains pragmatic. “Currently we are only focusing on safety and productivity improvement initiatives,” they noted. This distinction between survival and growth priorities captures the mine’s adaptive response to internal and external pressures, prioritising compliance, performance optimisation, and operational continuity amid ongoing sector instability.

The perspectives provided by KIR7 not only corroborate official documents but also enrich them with grounded operational insight.

Data pertaining to the key factors influencing the implementation of modernisation initiatives gathered from annual reports and participants are summarised in table 4.1 below.

Table 4.1: Triggers and objectives for mine modernisation vision

Key objectives and triggers driving the Modernisation Vision - Year 2017	
Trigger	**Objective**
Health and Safety Imperatives	Traditional mining practices posed significant risks and high injury rates, creating an urgent need for improved safety measures.
Escalating production costs and the drive for efficiency	Rising production costs due to outdated machinery and inefficient methods drove the need for mechanization and automation.
Interoperability Challenges	With systems unable to seamlessly exchange and interpret shared data, there was a need to introduce solutions that reduced variability.
Resilience and Competitiveness	Economic fluctuations, technological advancements, and regulatory shifts threatened sustainability, necessitating strategies to enhance resilience and long-term competitiveness.
Stakeholder Value Creation	Following its acquisition in 2006, the mine struggled to achieve sustainable profitability despite significant investments, requiring a clear demonstration of value creation for all stakeholders.
Development workforce of the future	Equipping the workforce for future demands through immersive training, VR simulations, and exposure to emerging technologies while fostering a culture of adaptability through effective change management strategies.

Source: Adapted from the company, (2018)

4.3 Perceptions on implications of technology deployment and how it reshapes the workforce.

This section explores Research Question 2 by analysing how technological implementation affects operations and labour dynamics.

4.3.1 Nature of Technological Deployment

The findings in this analysis are derived from both public documents supporting the case study and direct interviews with key stakeholders. Evidently, these resources underscore the influence of technology deployment on job evolution, as well as the skills needed to adapt to technological advancements in a typical underground gold mining operation. This was done through a critical first step that involved assessing the degree to which these technologies had become ingrained in operations. This involved thoroughly understanding the mine's modernisation strategies, which are often influenced by the modernisation drivers discussed in Section 4.1. Technological deployment at the mine is staggered and prioritised based on production needs as follows: *Horizon 1: Planning, scheduling, and monitoring* - Establishing a foundation for operational visibility through real-time data collection and leveraging business insights to plan for Horizon This would include including Safety/Water/Maintenance Management, Backfill monitoring/Mining control, and more.
Horizon 2: Executing - Transformational integration and optimisation of processes and systems over a three-to-seven-year period. This would include, including operating surface tele-remote rock breakers and LHDs.
Horizon 3: Reporting and analytics - Full delivery of a "Mine of the Future," incorporating advanced technologies and sustainable practices.
“We use technology where it makes sense – mainly in areas where it enhances safety or reduces repetitive tasks.” *(KIP – Technical Engineer)*

This highlights the dual imperative of using technology to protect workers from hazardous environments while maintaining operational efficiency.

Most operations use a hybrid model, blending human oversight with automated processes. Interviewees noted that full integration remains aspirational in many cases.

“There are pilots everywhere. But full integration? It remains a vision.” *(KIP – Project Lead)*

4.3.2 Integration of 5IR Technologies into mine operations

The analysis of Macnamara (2022), the 2018–2022 Social and Labour Plan, and annual reports from the mine reveals a progressive shift toward integrating 5IR technologies between 2017 and 2024. This transformation was driven by the organisation's "Mine of the Future" vision, which aimed to build a fully digital and automated mining environment supported by real-time analytics, IoT infrastructure, and advanced remote operations.
Key findings confirming integration include:

(a) Strategic Framework and Digital Infrastructure

The establishment of a Mine Operating Centre (MOC) marked a pivotal step. It enabled real-time visibility of operations and integrated human, equipment, and environmental systems. A phased rollout of technologies structured along four pillars: advanced analytics, automation, real time monitoring, and digital twin applications, allowed for a structured transition.
A robust IT/OT backbone was implemented, including over 60km of fibre optics and a Wi-Fi mesh network, supporting real-time data flow across critical underground areas.
SCADA systems and AI-based predictive tools were adopted to enhance efficiency and reduce unplanned disruptions.
Level 9 Collision Avoidance Systems (CAS), with integrated proximity detection and automatic stopping mechanisms, were being rolled out to meet regulatory compliance and enhance safety.
These infrastructural investments show a high degree of integration of 5IR technologies into core operational processes. This strategy was built on the vision outlined below and illustrated pictorially in figure 4.3.

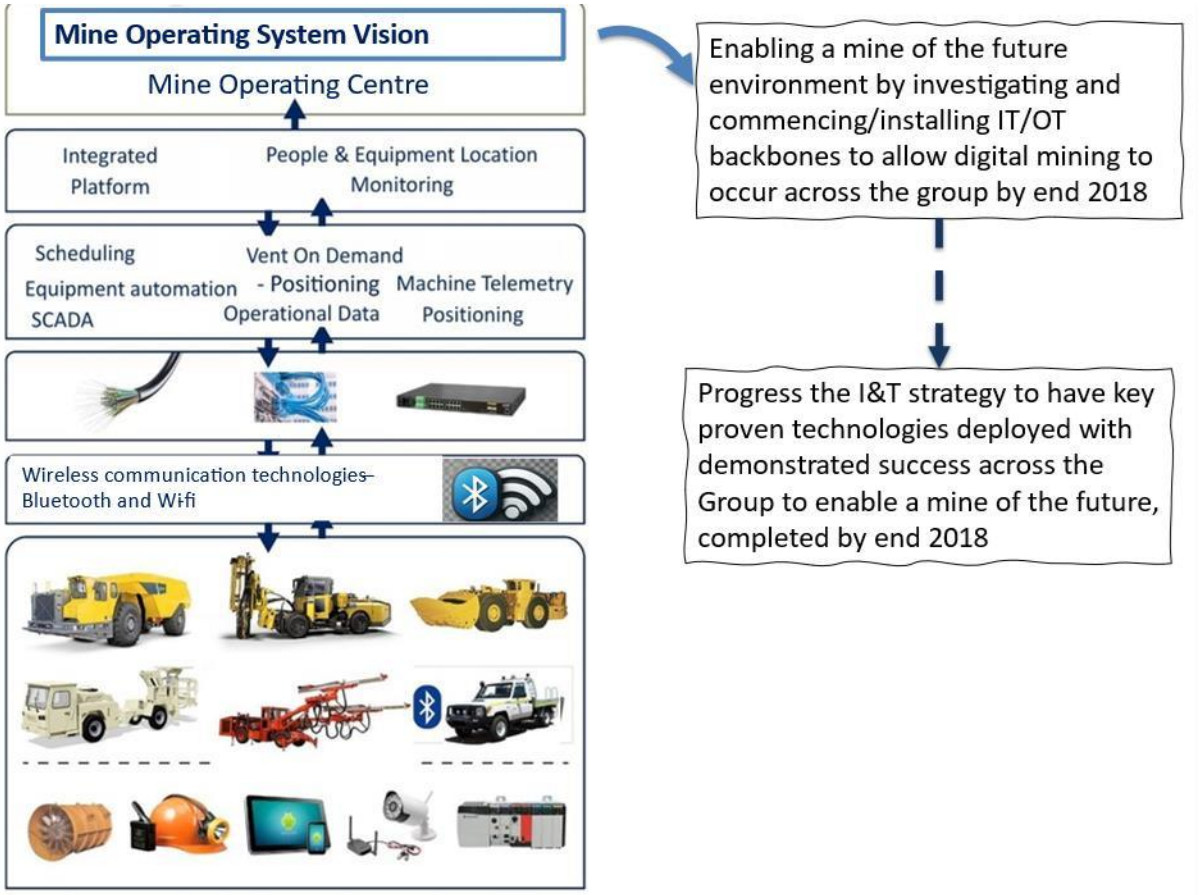


Figure 4.3: Mine operating system vision.
Source: Modified from (Place, 2024)

(b) Automation and Remote Operations

The deployment of tele-remote-controlled LHDs and rock breakers, along with automated haulage systems, has significantly reduced the need for human presence in hazardous zones. Real time fleet monitoring and control from surface centres has become standard.

According to interview data (KIP1), the shift to remote and tele-operated systems has led to enhanced productivity, reduced downtime, and safer working conditions. “Tele-Remote Operations: The mine has deployed tele-remote capabilities for rock breakers and Load-Haul-Dump (LHD) machines in strategic locations and this implementation will continue to expand. These systems have effectively enhanced productivity through continuous operations in hazardous or inaccessible areas, minimised downtimes and improved worker safety.



Figure 4.6: Mine operating system – Underground fleet management
Source: Place, (2024)

The move towards greater automation and tele-remote operations marks the next step in the mine's modernisation drive in accordance with the phased trajectory of its strategic framework.”. As such, “Mine System Architectural Design and Underground Automated Hauling Fleet System,” provides a detailed representation of the integration of underground development equipment, highlighting the practical application of automation advancements in mine operations.be a practical means of applying automation advances.

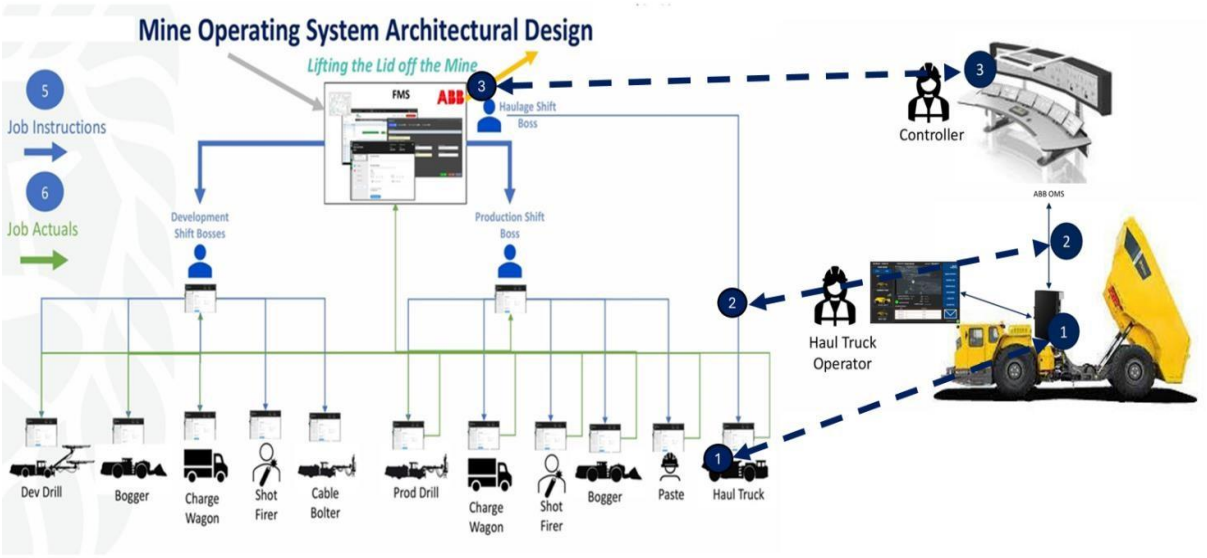


Figure 4.7: Mine System Architectural Design and Underground Automated Hauling Fleet System
Source: Modified from Place, (2024)

(c) Integrated Platforms and Decision-Making Tools

Centralising operations through a well-equipped central control centre with high-quality server architecture can reduce operational cost and exposure of workers in high-risk space. The facility combines underground data from tele-remote rock breakers, load-haul-dump machines, safety and maintenance management tools, water monitoring systems, and mining control apps. Central to this is an integrated work management platform linking the underground sensor networks to the control centre via the Command-and-Control Centre, real-time decision-making from a fully integrated underground environment. New technologies like UAV's, AI-driven misfire detection and automated wall damage identification improve post-blast assessment of shots, and the overall integrity of surrounding structures. Precision drilling, high-fidelity 3D modelling, augmented reality and big data analytics combine to improve the efficiency of blasts, minimising wasted energy and ore dilution. These advancements illustrate how 5IR technologies are redefining operational workflows, moving towards fully digitalised, data-driven mining environments. The image below illustrates a remote operating center where real-time monitoring, planning, and scheduling take place, showcasing the integration of digital

platforms that enhance operational visibility and decision-making in modern mining environments.



Figure 4.8: Mine integrated remote operations centre
Source: Macnamara, (2022)

(d) Operational Technologies and Device

This started with the deployment of an Internet of Things enabled sensor network and advanced digital infrastructure, enabling real-time communication across underground equipment, control centres and personnel. These sensors gather data about worker locations, equipment status, and environmental variables such as temperature, gas levels, and seismic activity. Using predictive maintenance systems for monitoring and predicting equipment failures to reduce unplanned downtime and improve overall efficiency. They also boast “man down detection” functionality, which automatically informs the control centre if a worker falls and stays down. Figure 4.5: Example of the new cap lamp solution, where employees can now be badged before entering underground operations. These lamps allow monitoring of personnel movements in real-time and direct communication with the command centre via a belt-pack messaging system.



Figure 4.5: New cap lamp with emergency warning and man down detection
Source: Newtrax,(2025)

(e) Network Backbone:

A future proof fibre optic backbone has been deployed that enables a direct connection from the surface control centre to underground communication hubs. With over 60 kilometres of fibre installed across all the most crucial locations, with a Wi-Fi mesh network fully integrated to enable undeterred data flow across all the critical spots. Wi-Fi access points and MineHops Mesh Network nodes enable real time data transfers.

(f) Advanced Analytics and Reporting

After integrating all operational aspects into the control centre, analytics solutions were implemented to gain more detailed knowledge of mine activity. Live dashboards are now monitoring production targets, process bottlenecks, and system inefficiencies. A location-based analytics module also enhances visibility with heat maps of high-traffic zones and hotspots with the potential for congestion and safety hazards.

(g) Automation of Key Processes

During the interviews with the mine officials, it was highlighted that the mine is adopting robotic process automation (RPA) to streamline repetitive administrative and operational tasks, thereby enhancing overall efficiency. While specific details on the implementation of RPA at the mine is limited on their September 2022 publication on the group's web site, according to Global Mining Magazine, the mining industry globally is increasingly embracing automation and robotics to transform operations (Global Mining News Magazine, 2025). The mine participants highlight that these technologies are at the forefront of efforts to create more efficient mining practices, siting, that in terms of the current status of the modernisation process, "Automation of Key Processes: The mine is adopting robotic process automation (RPA) to streamline repetitive administrative and operational tasks, enhancing overall efficiency".

4.3.3 The impact of technology adoption on the workforce

4.3.3.1 Employee productivity

Looking at the 2018-2022 period, through the annual reports, the period marked significant improvements in employee productivity at the mine. The annual reports reflect that gold production rose steadily during this time, with 9102 kilograms produced in 2021, increasing to 10,200 kilograms in 2022, and reaching 10,210 kilograms in 2023. The annual report of 2022 proclaims that these gains were driven by mechanised processes that reduced cycle times and increased output. Workers who transitioned to technical roles are reported to have played a critical part in this success, contributing to higher operational efficiency and enabling the mine to capitalise on its modernised systems. This impact is clearly reflected in the "Gold Production for the Operation 2015-2025: Actual vs Projected" graph, which illustrates the steady growth in gold production, showcasing the tangible results of these advancements and the mine's modernisation efforts.

Findings from the 2020 annual report indicate that production efficiencies, which was one reason cited as the key driver of mine modernisation. By 2020, there were some signs of a turnaround, with gains in production efficiency and cost management. Similarly, All-in Costs (AIC) fell by 1% in Rand terms to R655,826/kg (US$1,379/oz). The mine's financial

performance also improved markedly, generating net cash of R1. 4 billion (US$97 million) in 2021, a 157% leap from the R558 million (US$34 million) reported in 2020.

Such positive indicators helped restore investor confidence and further underpin the mine's position as a sustainable long-term operation.

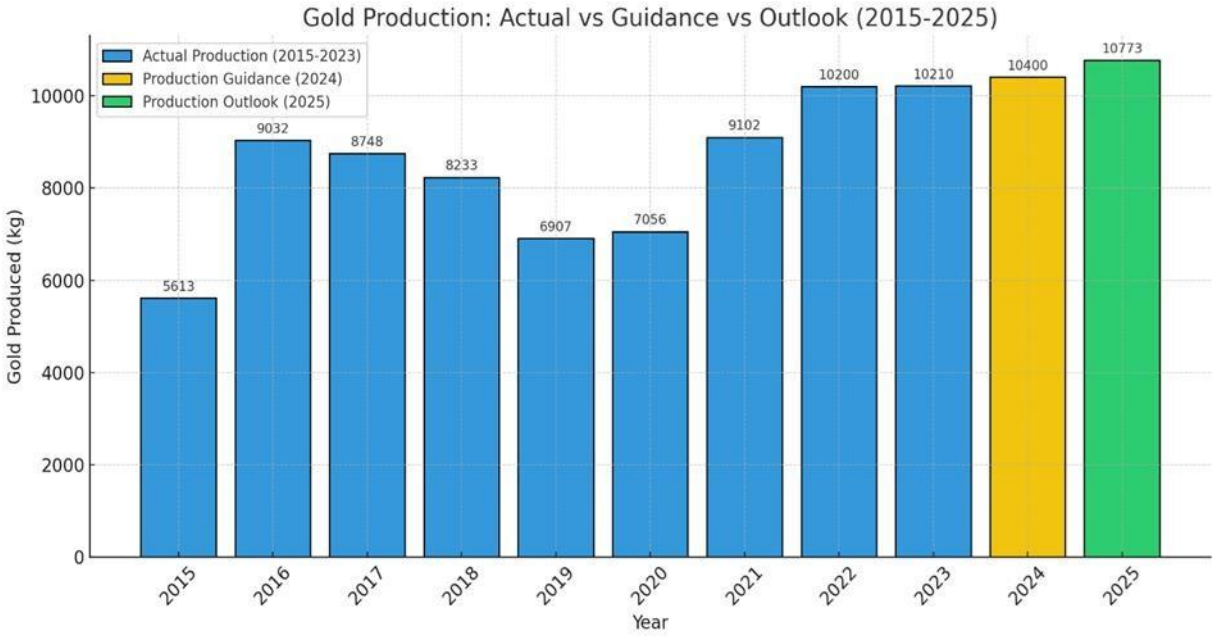


Figure 4.9: Gold production for the operation 2015-2025 Actual vs Projected.
Source: The company (2015, 206,2017, 2028, 2019,2020,2021,2022,2023.2024)

4.3.3.2 Precision and worker efficiency

The integration of advanced technologies in mining operations has significantly enhanced precision and worker efficiency by minimising human error and improving decision-making in high-stakes environments. Interview feedback confirms this trend across multiple dimensions of operational safety and productivity. When asked, *"In what ways do these technologies help reduce the risk of human error, thereby minimising the likelihood of operational blunders or mishaps?"*, KIR6 explained that technologies are playing a critical role in reducing human error by automating tasks, providing real-time feedback, and supporting decision-making. By minimising opportunities for human error, KIR6 noted, these advancements not only improve operational efficiency but also significantly reduce the risk of accidents.

Expanding on this, KIR7 emphasised the foundational role of a qualified workforce in reducing operational mistakes. In response to the question, *"How do the qualifications of workers influence the likelihood of human error in operations, and what measures are being taken to minimize this risk?"*, KIR7 pointed out that a well-trained and qualified workforce is more likely to make informed decisions, operate systems effectively, and follow safety protocols. However, even qualified personnel remain vulnerable to mistakes caused by stress, fatigue, or insufficient support.

To address these risks, KIR7 highlighted several organisational strategies, including continuous training programs focused on both emerging and legacy technologies, structured decision-making, and situational awareness. Furthermore, regularly updated Standard Operating Procedures (SOPs) ensure clarity and consistency in task execution. Regular reviews of incidents and near-misses also play a vital role in identifying root causes and reinforcing a culture of continuous learning and safety.

These insights collectively underscore the importance of a dual strategy in reducing human error: technological automation complemented by human skill development and organisational learning. The result is a safer, more efficient working environment where both machines and people contribute optimally to operational success.

4.3.3.3 Health and Safety Imperatives

Based on the information available from the group's annual reports and official documents, the Total Recordable Injury Frequency Rate (TRIFR) at the mine operation from 2017 to 2021 is high. This is presented in figure 4.10 below. Unfortunately, specific TRIFR data for the mine for the years 2022 and 2023 were not readily available in the sources used by the researcher. However, the 2023 annual report cited a 21% increase in safety engagement rate from 2022 to 2023, with near-miss incident reporting increasing from 1,577 in 2022 to 2,325 in 2023, attributed to concerted reporting efforts at the mine.

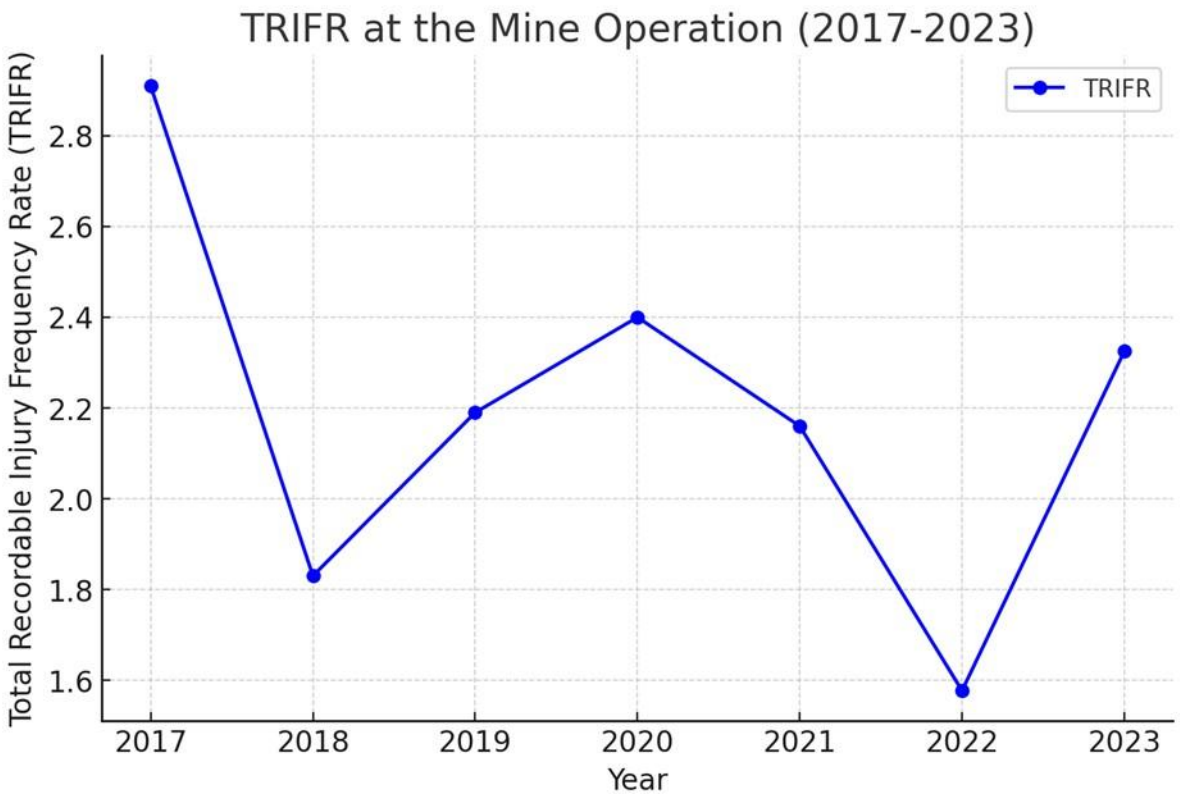


Figure 4.10: TRIFR from 2017-2023
Source: The company 2017, 2018,2019,2020,2021,2022,2023)

4.3.3.4 Expanding Workforce Inclusion through Technology

In response to the question, *"Are there opportunities for onboarding workers who may have been previously limited by physical or other attributes due to the implementation of new technologies?"*, Key Interview Respondent 6 (KIR6) affirmed that the implementation of advanced technologies—such as automation, remote operation systems, and robotics—has indeed created unique opportunities for a more inclusive workforce. KIR6 noted that these technologies enable individuals with physical limitations to participate in mining operations by shifting tasks from physically demanding environments to digitally controlled settings. As a result, roles that were once inaccessible due to physical constraints are now open to a broader talent pool, thereby fostering greater workforce diversity and inclusion across the sector.

4.3.3.5 Navigating the Employment Landscape: Automation, Job Security, and Workforce Trends

(a) Mining Sector Employment Trends in the Age of Automation

As demonstrated in Section 4.3.2, the adoption of 5IR technologies has transformed traditional mining operations, fostering a more interconnected, intelligent, and responsive working environment. These technological changes inevitably influence the workforce, prompting a need to examine both the short- and long-term implications for employment within the sector. One of the central concerns addressed in this study is the complex interplay between automation and employment trends in South Africa's mining industry. While projections related to 4IR technologies have fuelled widespread concerns about imminent job losses and large-scale displacement, actual employment data presents a more nuanced picture.

Table 4.2 offers a comparative analysis of CEIC mining employment data and projections made by researchers regarding automation and its potential impact. This comparison highlights key trends in employment growth, national unemployment rates, and the projected effects of automation on the mining workforce. It provides insights into the resilience of the mining sector and the evolving nature of workforce dynamics in the context of technological change.

Table 4.2: A Comparison of CEIC Mining Employment Data and Researchers' Projections on Job Displacement

Category	CEIC Observation	Researchers' Claim	Comparison
Mining Sector Employment Growth (CEIC vs. the 4IR Concerns)	Employment grew from 344,737 in Oct 2021 to 454,283 in Jan 2024.	87,000 jobs expected to be lost in the short term; 20% of jobs automated by 2030.	CEIC data contradicts short-term job loss claims as employment grew steadily.
Unemployment rate Peak vs. Mining Employment Trends	Mining employment reached 443,520 in Q3 2023 despite unemployment peaking nationally at 41.2%.	South Africa's unemployment rate reached 41.2% in Q3 2023.	Mining sector appears resilient compared to other sectors experiencing high unemployment.
Automation's Projected Impact vs. Actual Data	Mining employment trends show no immediate decline, suggesting automation effects have not materialised yet.	41% of all jobs in South Africa and 20% of mining jobs projected to be displaced by 2030.	Automation's displacement effects may not yet have occurred or have been offset by other factors.

Job Creation in Mining vs. Excerpt Analysis	Mining employment shows consistent growth, supporting job creation despite the 4IR concerns.	While the 4IR may displace jobs, new opportunities will emerge in the long term.	Job creation observed in CEIC data aligns with the excerpt's long-term projection of new opportunities.

Source: Author's own compilation - Adapted from (Statista, 2024)

(b) Gold Mining Subsector: Automation, Job Security, and Evolving Workforce Trends

In contrast to the broader mining sector, which shows generally positive employment trends, the gold mining subsector presents a more complex picture. The introduction of automation and other modern technologies has prompted significant structural shifts in its workforce. This section explores how these developments have impacted job security and workforce composition, highlighting key trends and implications specific to the gold mining context.

(c) Workforce profile before modernisation

The Social and Labour plan report of 2018-2022 for the mine under study supported by the responses from the interviews provided the research with information, such as: Education Levels for Employees at 18 June 2018, workforce roles before modernisation, Learnerships, bursaries, core skills training programmes. Findings from these sources outline the jobs before modernisation as illustrated in table 4.2

Table 4.2: Occupational categories and requirements before modernisation

Job Title	Mandatory Requirements	Preferred Requirements
Senior Operations Manager	Mine Managers Certificate, Professionals Registrations, Safe Production Rules, Health and Safety course	Mining Degree / Diploma / GIBBS - MDP / LDP / POLC course
Operation Manager	Mine Managers Certificate, Professionals Registrations, Safe Production Rules, Health and Safety course	Mining Degree / Diploma / GIBBS - MDP / LDP / POLC course
Geologists	Bachelor's degree in Geology or Earth Sciences, Postgraduate degree may be a requirement for advanced roles. Registration with the South African Council for Natural Scientific Professions (SACNASP).	Knowledge of GIS and mapping software (e.g., ArcGIS, AutoCAD). Understanding of mineral exploration techniques and geotechnical analysis. Strong mathematical, analytical, and problem-solving abilities. Familiarity with mine

Job Title	Mandatory Requirements	Preferred Requirements
		safety regulations and compliance standards.
Winding Engine Driver (Core and Critical Skills)	Winding Engine Driver Certificate of Competency (issued by the Department of Mineral Resources and Energy - DMRE) Minimum 3–5 years of experience operating hoisting and winding systems. Knowledge of Mine Health and Safety Act (MHSA) and occupational safety standards. Medical fitness and psychometric assessment clearance	Experience in modernised winder systems (e.g., friction hoists, drum hoists) Additional certification in electromechanical systems or maintenance. Exposure to automation and digital monitoring of hoisting operations
Metallurgist (Core and Critical Skills)	BSc / BEng / BTech in Metallurgical Engineering, Chemical Engineering, or Extractive Metallurgy. Understanding of metallurgical test work, process control, and mineral processing techniques. Knowledge of mine safety regulations and environmental compliance	Postgraduate degree in Metallurgy, Hydrometallurgy, or Mineral Processing. Experience in process optimisation, metallurgical accounting, and data analytics. Certification in Lean Six Sigma or process improvement methodologies
Environmental Officers (Core and Critical Skills)	Bachelor's degree in Environmental Science, Environmental Management, or a related field. Registration with the Environmental Assessment Practitioners Association of South Africa (EAPASA) is advantageous	Understanding of environmental impact assessments (EIA) and sustainability practices. Knowledge of mining legislation and environmental laws. Data analysis and report writing. GIS and remote sensing for environmental monitoring.
Engineers (Core and Critical Skills)	Bachelor's degree in mining, Mechanical, Electrical, Civil, or Metallurgical Engineering. Registration with the Engineering Council of South Africa (ECSA) for professional recognition. Internship or graduate training programme in mining operations.	Strong technical knowledge of mining processes and equipment. Proficiency in computer-aided design (CAD) software. Problem-solving and critical thinking. Knowledge of automation, AI, and 5IR technologies in mining.

Job Title	Mandatory Requirements	Preferred Requirements
Rock Engineer	BSc / BEng / BTech / National Diploma in Mining Engineering, Geology, or Rock Engineering. Chamber of Mines Rock Mechanics Certificate. Registered with the South African Institute of Rock Engineering (SANIRE)	Postgraduate qualification in Rock Engineering or Geotechnical Engineering. Experience in numerical modelling software (e.g., MAP3D, FLAC, Rocscience). Strong knowledge of mine design, seismic monitoring, and geotechnical risk assessments
Resource Geologist	BSc (Hons) / MSc in Geology, Earth Sciences, or equivalent. GSSA (Geological Society of South Africa) membership and SACNASP (South African Council for Natural Scientific Professions) registration. Proficiency in geological modelling software (e.g., Leapfrog, Datamine, Surpac)	Competent Person (CP) accreditation under SAMREC / JORC / NI 43-101 reporting standards. Experience in exploration, resource classification, and QA/QC processes. Strong statistical and geostatistical skills for resource estimation
Mine Planner	BSc / BEng / BTech / National Diploma in Mine Engineering, Geology, or Mine Surveying. Proficiency in mine planning software (e.g., MineSched, Deswik, Datamine, Surpac) Strong understanding of ore reserve estimation, cut-off grade calculations, and production scheduling	Postgraduate qualification in Mining Engineering or Mine Planning Registration with ECSA (Engineering Council of South Africa) as a Professional Engineer (Pr Eng) Experience in long-term strategic mine planning and cost optimisation
Unit Managers	Mine Managers Certificate, Professionals Registrations, Safe Production Rules, Health and Safety course	Mining Degree / Diploma / GIBBS - MDP / LDP
Mine Overseers	Mine Overseer Certificate, Safe Production Rules, Health and Safety course	Mine Managers Certificate / Grade 12 / GIBBS - MDP / LDP
Drill Rig Operators / Support Rig Operators / Long Hole Rig Operators	Comp A, Safe Production Rules, Health and Safety course	Blasting Certificate, Grade 10.
LHD Operator	Comp A, Safe Production Rules, Health and Safety course	Blasting Certificate, Grade 10.
Dump truck Operators / Grader Operators / Dozer Operators	Comp B, Safe Production Rules, Health and Safety course	ABET 4

Job Title	Mandatory Requirements	Preferred Requirements
Scaler Operator / Utility Vehicle Operator / Charmec Operator / Spraymec Operator	Comp B, Safe Production Rules, Health and Safety course	ABET 3
Impact Breaker Operators	Comp B, Safe Production Rules, Health and Safety course	ABET 2
General Labourer	Comp B, Safe Production Rules, Health and Safety course	ABET 1
Health and Safety Officers (Core and Critical Skills)	National Diploma or Degree in Occupational Health and Safety, Environmental Health, or a related field. SAMTRAC or COMSOC certification. Registration with the South African Institute of Occupational Safety and Health (SAIOSH).	Strong understanding of Mine Health and Safety Act (MHSA). Risk assessment and incident investigation skills. Ability to develop and enforce safety protocols.
Crew Leader	Blasting Certificate, Safe Production Rules, Health and Safety course.	Leadership and team management. Knowledge of mine planning and scheduling. Strong decision-making and crisis management abilities.
Artisans and Technicians (Critical Core Skill)	Technical or vocational training in fitting, boiler making, electrical, or mechanical trades. Trade Test Certification (Red Seal) from a recognized institution. Apprenticeship in a mining environment.	Ability to repair and maintain mining equipment. Understanding of hydraulics, pneumatics and automation. Strong troubleshooting and diagnostic skills.
Human Resources	Diploma or Degree in Human Resources, Business Administration, or Industrial Psychology.	Knowledge of labour laws and union negotiations. Strong administrative and organisational skills.
Payroll Officers	Training in payroll software such as SAP, SAGE, or Pastel Payroll.	Payroll processing and employee benefits management.

Source: Adapted from 2018-2022 SLP's and Interviews

The Social and Labour plan report of 2018-2022, supported by the responses from the interviews provided the research with historically revealing that, the mining workforce comprised roles heavily reliant on physical labour and practical, on the job training. For

example, the traditional miner and drill rig operator required only a Grade 12 qualification, supplemented by practical training and, in some cases, a Blasting Certificate (South African Qualifications Authority, 2024) Similarly, roles such as Shift Supervisor, Artisan and Technician, and Health and Safety Officer were defined by basic formal qualifications and extensive hands-on experience. Other roles, such as those of Geologists, Engineers, Surveyors, Logistics Coordinators, and HR and Payroll Officers, demanded more advanced qualifications yet were firmly rooted in conventional industrial practices that emphasised physical presence and manual oversight.

Table 4.3: Mine workforce's education levels

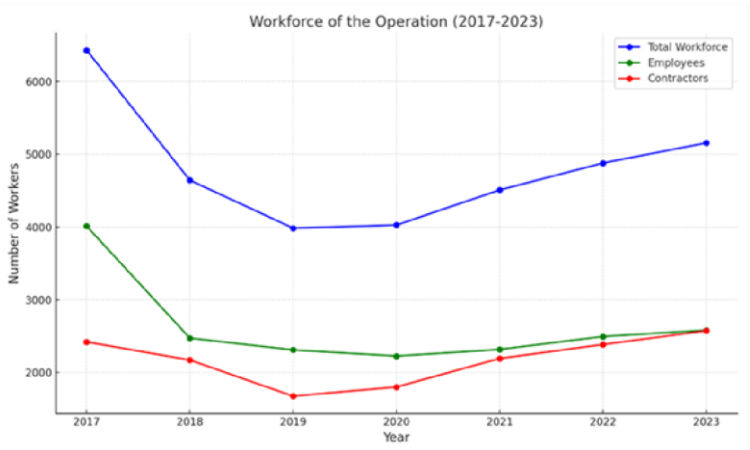
Education Levels for Employees at 18 June 2018			
Band	**NQF**	**Education Level**	**Employees**
General Education and Training (GET)	1	No Schooling / Unknown	-
	1	Grade 0 / Pre	129
	1	Grade 1 / Sub A	0
	1	Grade 2 / Sub B	18
	1	Grade 3 / Std 1 / ABET 1	93
	1	Grade 4 / Std 2	69
	1	Grade 5 / Std 3 / ABET 2	89
	1	Grade 6 / Std 4	94
	1	Grade 7 / Std 5 / ABET 3	170
	1	Grade 8 / Std 6	160
	1	Grade 9 / Std 7 / ABET 4	194

Education Levels for Employees at 18 June 2018			
Band	**NQF**	**Education Level**	**Employees**
Further Education and Training (FET)	2	Grade 10 / Std 8 / N1	286
	3	Grade 11 / Std 9 / N2	467
	4	Grade 12 / Std 10 / N3	1242
Higher Education and Training (HET)	5	Diplomas / Certificates	445
	6	First degrees / Higher diplomas	105
	7	Honours / Master's degrees	46
	8	Doctorates	2

Source: Social and Labour plan 2018

The mine's Social and Labour Plan (SLP) for June 2018 categorised employees by gender, race and education levels. However, since demographic segmentation is not central to this study, the workforce data has been consolidated into a composite analysis focused on education categories as illustrated in table 4.3

(d) The workforce profile of a modernised mine



Workforce of the operation 2017-2023			
Year	Total Workforce	Employees	Contractors
2017	6432	4012	2420
2018	4643	2472	2171
2019	3984	2310	1674
2020	4027	2226	1801
2021	4510	2317	2193
2022	4880	2495	2385
2023	5156	2582	2574

Figure 4.11: Workforce size of the operation - 2017 to 2023
Source: Extracted from The company 2017, 2018,2019,2020,2021,2022,2023)

Findings from annual reports spanning 2017 to 2023 reveal that as automation became a central feature, the workforce composition underwent a significant transformation. In 2017, the total workforce stood at 6,432, comprising 4,012 employees and 2,420 contractors. Following restructuring driven by modernisation, the workforce declined to 4,643 in 2018, with 2,472 employees and 2,171 contractors. This trend continued in 2019, with the total workforce decreasing to 3,984, comprising 2,310 employees and 1,674 contractors. In 2020, the workforce slightly increased to 4,027, with 2,226 employees and 1,801 contractors. By 2021, the total workforce had grown to 4,510, consisting of 2,317 employees and 2,193 contractors. The upward trend persisted in 2022, reaching 4,880, with 2,495 employees and 2,385 contractors, and continued into 2023, where the workforce stood at 5,156, including 2,582 employees and 2,574 contractors. While the overall workforce rebounded in later years, automation led to the gradual phasing out of manual, labour-intensive roles, creating a demand for more technical and specialised positions.

Table 4.3: Critical roles and function for a modernised mine

Job Title	Entry Level Qualification	Additional Skills	Job Description
Automation Engineers	Bachelor's degree in Electrical Engineering, Mechanical Engineering, Mechatronics, or Computer Science.	PLC programming, robotics, control systems, and industrial automation.	Design, maintain, and optimize automated systems, including autonomous vehicles and robotic drills.
Artificial Intelligence (AI) Specialists	Bachelor's degree in Computer Science, Data Science, Artificial Intelligence, or a related field.	Machine learning, deep learning, Python, TensorFlow, and big data analytics.	Develop and manage AI models for predictive maintenance and operational efficiency.
Data Analysts	Bachelor's degree in Statistics, Mathematics, Computer Science, Economics, or a related field.	SQL, Python, R, Power BI, and data visualization.	Analyse big data from sensors and IoT devices to improve decision-making and productivity.
Digital Transformation Leads	Bachelor's degree in Business Administration, Information Technology, or a related field.	Change management, digital strategy, emerging technologies, and leadership.	Oversee the integration of digital solutions, ensuring alignment with strategic goals.
IT and Cybersecurity Specialists	Bachelor's degree in Computer Science, Information Technology, or Cybersecurity.	Certifications: CISSP, CISM, CEH, or CompTIA Security+.	Protect critical digital infrastructure from cyber threats.
IoT Technicians	Diploma or Bachelor's degree in Electronics, Mechatronics, or Computer Science.	IoT device programming, cloud computing, networking, and troubleshooting.	Manage interconnected devices and systems, ensuring seamless data exchange.
Human Factors Specialists	Bachelor's or Master's degree in Psychology, Ergonomics, Industrial Engineering, or Human-Computer Interaction.	Cognitive science, usability testing, and human centred design.	Optimize interactions between workers and machines to enhance safety and efficiency. Ergonomic Improvements – New drill designs and exoskeleton technology are reducing the physical strain on operators.
Change Management Consultants	Bachelor's or Master's degree in Business Administration, Organizational Psychology, or Human Resources.	PROSCI Change Management Certification or Lean Six Sigma.	Guide workforce adaptation to new technologies and processes.
Sustainability Officers	Bachelor's or Master's degree in Environmental Science, Sustainability, Business, or Engineering.	ESG (Environmental, Social, and Governance), compliance, and sustainability reporting.	Implement strategies to minimize environmental impact and improve energy efficiency through green technologies.

Job Title	Entry Level Qualification	Additional Skills	Job Description
Ethics and Compliance Managers	Bachelor's or Master's degree in Environmental Science, Sustainability, Business, or Engineering.	ESG (Environmental, Social, and Governance), compliance, and sustainability reporting.	Ensure the ethical use of AI and adherence to legal standards in mining operations.
Smart Equipment Operators	Bachelor's or Master's degree in Law, Business Ethics, Compliance, or Governance.	Certified Compliance and Ethics Professional (CCEP).	Operate and monitor advanced machinery via digital interfaces or remote systems. **Technical Diploma or Certification** in Machine Operations, Mechatronics, or Robotics.
Innovation Strategists	Diploma or Bachelor's degree in Electronics, Mechanical Engineering, or Industrial Automation.	Hands-on experience with AI-driven equipment and robotics.	Drive continuous improvement by identifying and integrating emerging technologies.
Workforce Development Specialists	Bachelor's or Master's degree in Business Innovation, Entrepreneurship, or Strategic Management.	Design thinking, business model innovation, and technology foresight.	Design and implement training programmes to reskill and upskill employees for new roles.

Sources: Extracts from Interviews

The interview responses gave insights into how the implementation of autonomous trucks, teleremote operation of equipment, and predictive maintenance systems has led to the creation of new positions such as Smart Equipment Operators, data analysts, and IoT technicians. At the same time, traditional roles like equipment operators and maintenance technicians have undergone significant transformation to align with these new technological frameworks. These records illustrate the ways in which technological interventions have rendered certain job roles obsolete while simultaneously creating opportunities for upskilling, workforce retention, and enhanced safety measures. In response to the two questions, "Following the 80/20 Pareto principle, what roles and positions were essential for the mine's operations prior to modernisation? And, "What roles and positions will be essential for the modernised mine", the responded gave a list of such roles as itemised in table 4.3.

(e) Workforce composition and skills gap

As we venture into gaining insights into the evolution of the mine workforce, it became necessary to draw findings from the past five years' annual reports, which reflect a gradual refinement in workforce profiling, planning, and recruitment policies. Insights from interviews

with key stakeholders provide a foundational understanding of how modernisation, driven by the adoption of cyber-physical systems, has influenced employment trends. It is worth noting that 2018 was the only year with relevant, publishable statistics, limiting further calculations and extrapolations to that dataset. Findings revealed a significant lag in training and upskilling efforts, with training programmes often being reactive—targeting employees already in transition rather than anticipating future needs. Key Interview Respondent 1 (KIR1) confirmed that while pre-assessment processes are in place for new recruits and skill requirements evolve based on shifts in mining methods, there remains an ongoing need to evaluate hard-to-fill vacancies, which informs scarce skills analysis and triggers plans to address gaps.

Additionally, KIR3 stressed the growing importance of data analysis capabilities, noting that although modernised operations now extract significant amounts of data, much of it remains underutilised due to a lack of employee data literacy. In terms of upskilling, KIR4 highlighted the shift toward more digitally designed training content, blended learning approaches, and immersive training experiences to enhance employee engagement and learning outcomes. However, challenges remain in aligning training offerings with operational realities, especially when training is outsourced. The interviews also highlighted limitations in workforce adaptability due to literacy levels, particularly in the transition from conventional to mechanised mining, and the need for discipline-specific cross-functional training, which is constrained by regulatory requirements. While internal re-skilling is prioritised, there remains an acknowledged reliance on external recruitment for highly specialised roles, dependent on the availability of training providers capable of meeting new competency demands. These insights point to a growing case for embedding continuous learning ecosystems within mining operations to future-proof workforce capabilities and bridge the existing skills gap in an era of rapid technological transformation.

KR3’s assertions are complemented by the 2018-2022 SLP, stating that the roles classified as hard-to-fill typically require formal qualifications, often with mathematics as a key subject. To bridge this gap, the SLP show that the mine has implemented various skills development initiatives, including learnerships and bursaries, which are strategically aligned with its Employment Equity targets. Special attention is given to occupations in senior and operational management, professionally qualified and experienced specialists, mid-management (also referred to as critical core skills), and skilled technical roles such as junior management, supervisors, foremen, and superintendents. Through these targeted efforts, the mine aims to

progressively close the skills gap and ensure a sustainable, well-equipped workforce for the future.

To better understand the extent of the challenge and project future workforce needs, a skills gap graph was generated using data from the mine's 2018–2022 SLP. This graph illustrates the relationship between projected skills coverage over time and the anticipated skills gap. The input parameters used include all training programmes, positions undergoing transformation or becoming obsolete, as well as emerging roles and hard-to-fill vacancies affecting the mine (see Appendix). These positions have been identified through the mine's Workplace Skills Programme (WSP), a mandatory requirement under the South African Skills Development Act, submitted alongside the Annual Training Report (ATR) to the Mining Qualifications Authority (MQA).

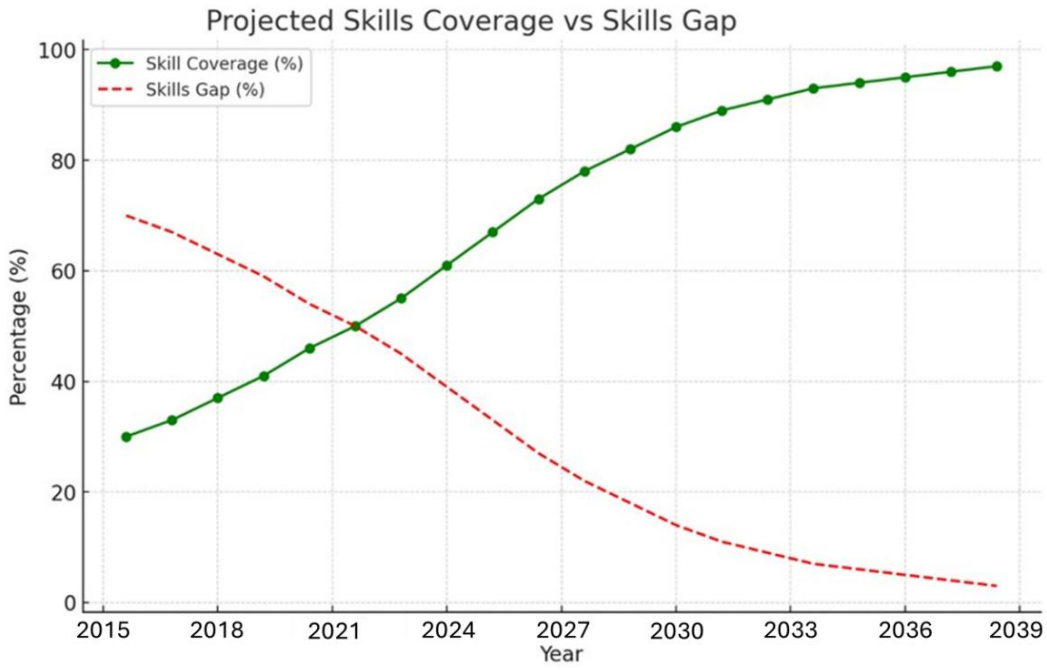


Figure 4.11: Projected skills coverage versus skills gap for the years 2017-2037
Source: Author's own work

According to historical data drawn from the 2018 - 2022 Social and Labour Plan (SLP), only about 30% of the workforce met the required skill levels in 2018. When projections were calculated, using the formula outlined in Section 1.8, it was estimated that by 2023, the skills gap would have narrowed to roughly 50%. A significant acceleration in skills development is

expected by 2030 as training and education efforts intensify, with projections indicating that by 2037, approximately 95% of the workforce will possess the necessary skills.

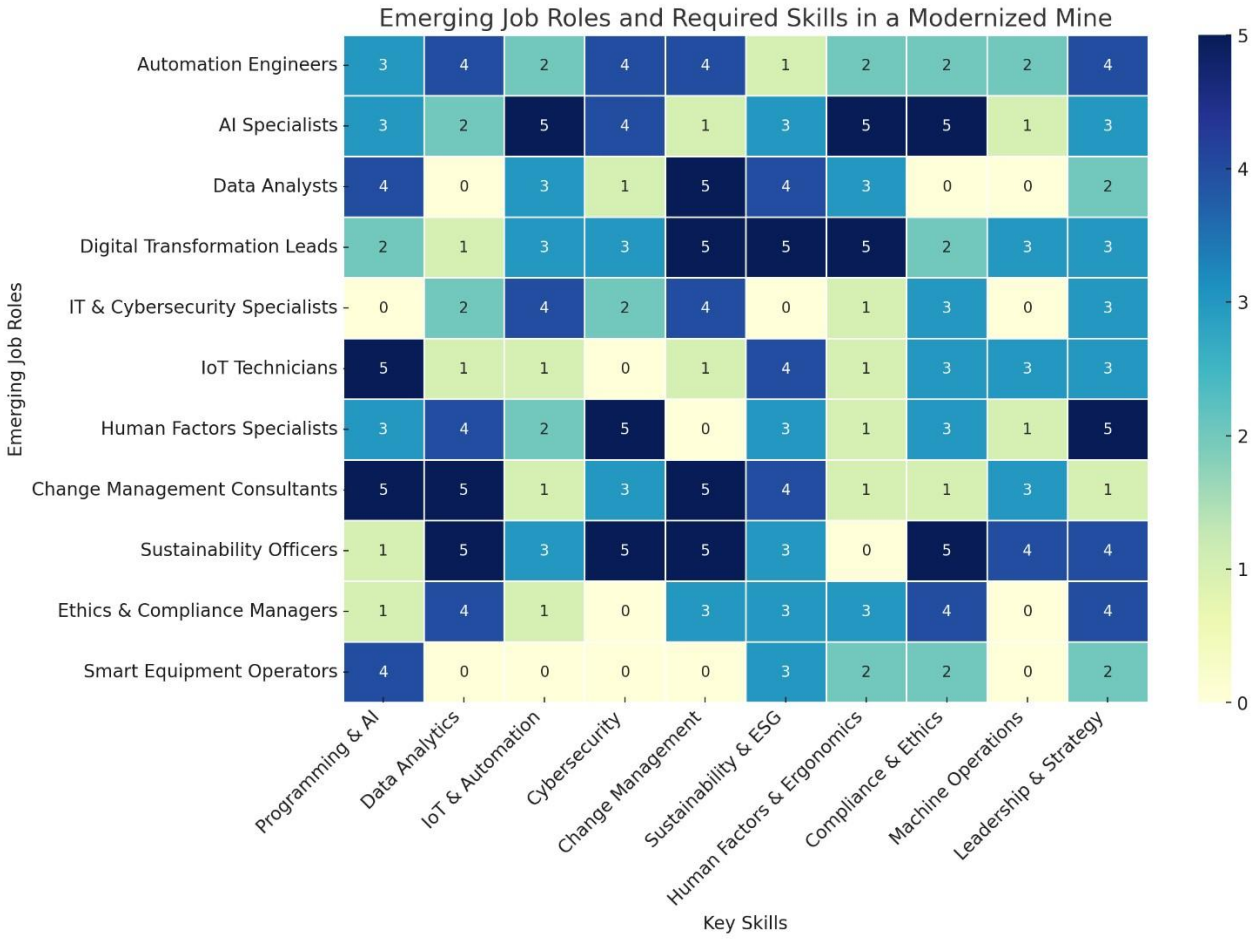


Figure 4.12: Heatmap for emerging roles for the years 2017 - 2037
Source: Author's own work

(f) Quantifying Workforce Composition and Modernisation Trajectories (2018–2022)

To deepen the understanding of how this evolving skills landscape aligns with structural workforce changes, the following section quantifies the workforce composition post-restructuring and maps its alignment with the mine's modernisation trajectory. Figure 4.13 presents a quantitative breakdown of workforce distribution in 2018, after the restructuring, classifying employees into four primary categories. Using available data on the 2018-2022 SLP on job titles and roles before modernisation, projected roles for a modernised mine, current education levels, training programmes, graduate output, planned trainee intakes from 2018 to 2022, and employment equity plans, we derived the following workforce composition: The General Labour and Core Skills category, accounting for 55% of the workforce, primarily

consists of manual labourers and equipment operators engaged in repetitive, physically demanding tasks. The Mid and Critical Core Skills category represents 30% of the workforce, comprising engineers, technicians, and supervisors. Senior Management, making up 10%, assumes leadership responsibilities, while the remaining 5% is attributed to Emerging Roles, reflecting shifts in workforce demands due to automation and digital integration.

These classifications highlight the historical reliance on specific skill sets while underscoring opportunities for workforce transformation in response to modernisation. Figure 4.10 illustrates a workforce replacement vs. retraining analysis for jobs at the mine from 2017-2037. The green section represents the percentage of workers that can be retrained, while red indicates roles that will likely be replaced.

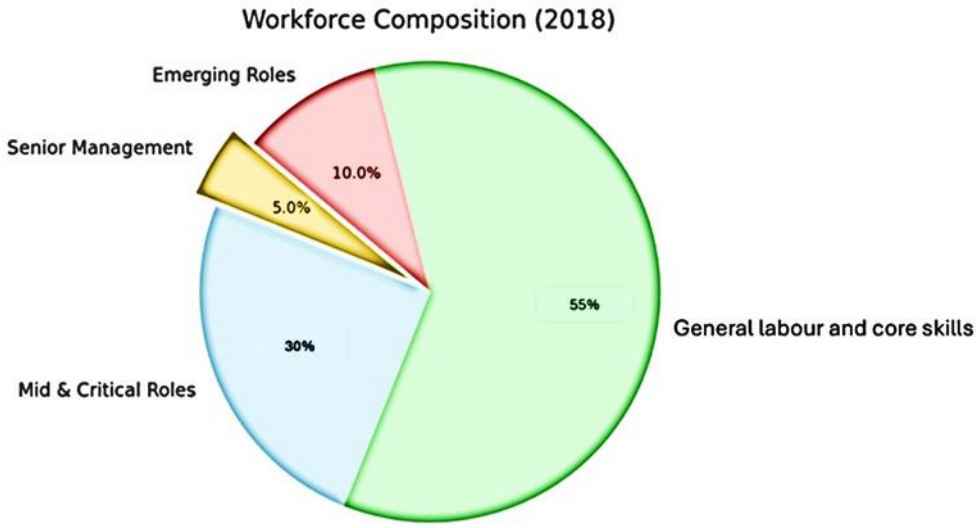


Figure 4.13: Workforce distribution at the mine after workforce restructuring
Source: Adapted from The Company, (2018)

While this composition provides a snapshot of the workforce at a particular point in time, it is equally critical to assess how each category is positioned in relation to automation trends and the resulting need for targeted reskilling and career transition strategies.

General Labour and Core Skill has the greatest risk for displacement as a result of automation, with estimates suggesting that 80% of these roles could be automated away. More effective efforts to reskill and upskill people targeted at specific populations are necessary in order to avoid mass scale job losses. To transition careers, training programmes should emphasise on digital literacy, mechanical proficiencies and automation-related skills. The mid and critical core skills category roles are also changing as a result of automation, but they are more

malleable given moderate upskilling. About 60% of employees in this category can be retrained through specialised programmes in automation control, predictive maintenance and data analytics, allowing them to remain relevant in a changing industry. However, 10% of the workforce, Senior Management, is least likely to be affected by automation. Leadership positions, at least 80%, are expected to remain wholly intact. Automation, while streamlining operations, does not replace human-driven leadership or strategic decision-making. Nevertheless, continued focus and training towards leadership in areas of digital transformation, as well as technological innovation will be necessary to remain competitive.

Emerging Roles, such as AI integration specialists, cybersecurity experts, and robotics maintenance personnel, are projected to expand significantly. Approximately 90% of these positions are new yet trainable, emphasising the need for proactive skills building initiatives. Based on these findings, it is evident that establishing strong educational pathways and technical training programmes will be crucial in preparing the workforce for these emerging opportunities

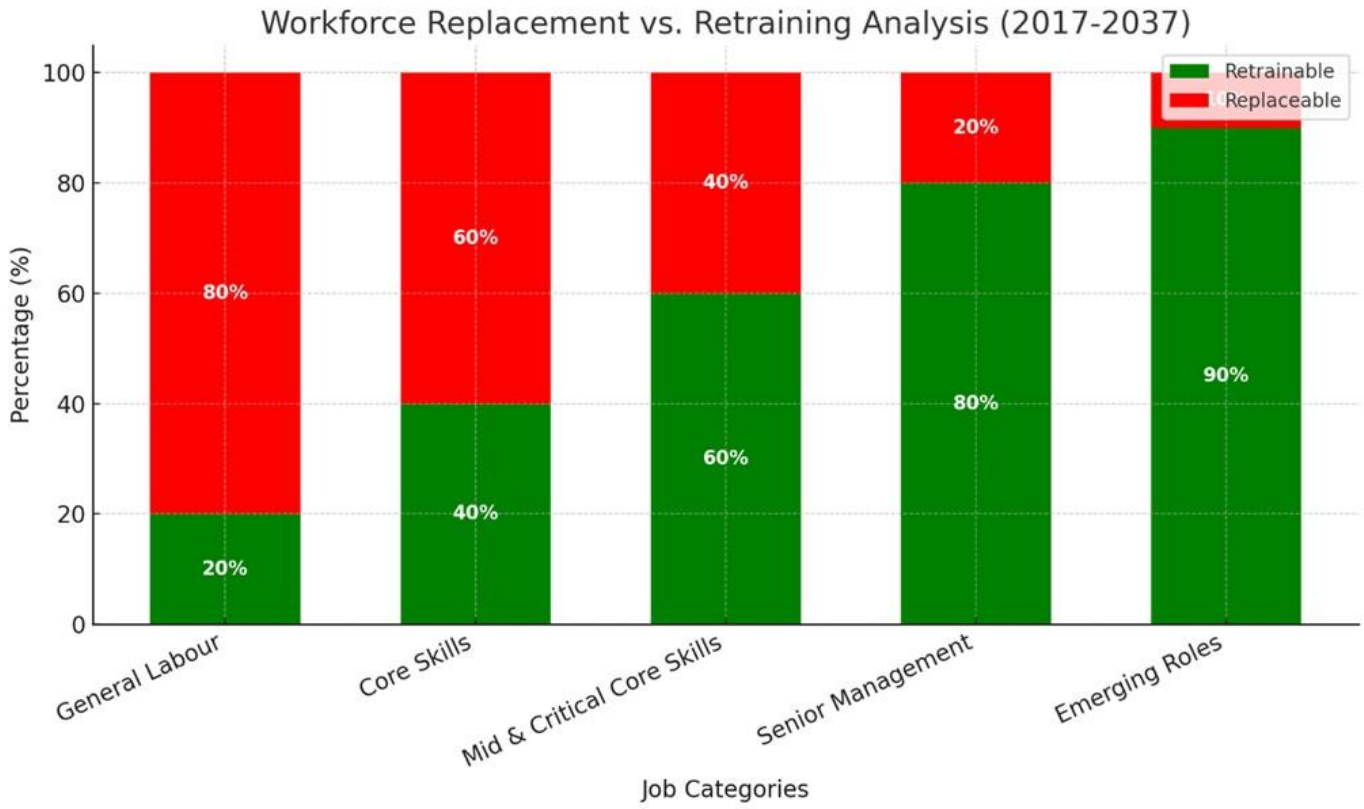


Figure 4.14: Workforce replacement vs. Retraining analysis
Source: Author's own work

4.4 Optimising Workforce Planning Amidst Technological Change

4.4.1 Introduction

This section examines the evolution of workforce planning in the mine over a twenty-year period (2017–2037), assessing both existing and necessary strategic measures for optimised task allocation and adaptability. Findings from the mine's annual reports (2018–2023) indicate a progressive refinement in workforce planning and recruitment policies. While notable strides have been made in aligning workforce strategies with technological advancements, further refinement is essential to ensure long-term sustainability. Given the mine's commitment to a people centric modernisation strategy, this study evaluates the extent to which workforce reorganisation preserves worker well-being while enhancing adaptability. A key consideration is ensuring that modernisation efforts do not merely displace traditional roles but instead facilitate a structured transition into new, digitally integrated functions (Macnamara, 2022).

4.4.2 People-Centric Approach to Technological Transformation

Asked if the mine has prioritised human dimensions over the technology strategy and set clear technological transformation targets to experience a smoother transition to 5IR technologies, the KIR4 indicated that, "Modernisation *within the mine extends beyond the deployment of new technologies; it is fundamentally a change management process. To mitigate workforce disruptions, the mine has adopted a phased implementation strategy that integrates technology deployment with workforce preparation initiatives. These include:*

- *Enhanced communication strategies: Proactive engagement through structured digital surveys and regular workforce briefings to assess employee sentiment.*
- *Immersive training methodologies: Use of virtual reality (VR) and simulation-based learning to accelerate skills acquisition.*
- *Gradual onboarding processes: Incremental adoption of new digital tools, ensuring employees perceive technology as an enabler rather than a disruptor (Macnamara, 2022). By fostering a culture of adaptability and continuous learning, the mine aims to ensure that employees remain integral to its long-term operational strategy."*

4.4.3 Workforce Strategy and Digital Transformation: Towards the Mine of the Future

Findings from the interviews inform us of the importance of workforce reorganisation in ensuring that automation, sustainability, and operational efficiency objectives are achieved.

Accordingly, the annual reports from the 2018 to 2023 five-year period indicate a gradual refinement in workforce planning and recruitment policies.

The question was asked, “Could you please provide insights into the company's long-term strategic approach to planning the workforce structure and determining the number and qualifications of the workforce?” To which KIR1 responded:

“*Alignment with Strategic Goals*

- *Our workforce planning is closely aligned with the company’s goals for increased automation, sustainability, and profitability.*

- *Anticipating future technological, regulatory, and market trends to shape the workforce structure.*

Skills and Qualifications Mapping

- *Conducting skills audits to identify gaps in existing competencies.*

- *Mapping skills required for roles like automation specialists, data scientists, and sustainability officers.*

- *Emphasising the need for employees with cross-functional expertise (e.g., combining mining knowledge with IT or AI skills).*

Workforce Structure and Numbers

- *Incorporating a mix of full-time, contract, and remote workers to adapt to dynamic operational needs.*

- *Preparing the next generation of leaders by identifying and nurturing talent.”*

- However, the respondent, concedes that aligning these processes with rapid technological advancements remains a challenge, calling for a more precise alignment with technological advancements remains necessary. He sites, “Focus on recruitment policies and workforce planning, procedures and processes has led to better selection of new employees, however there is a lot more work needed in this space”

It is evident, therefore, that the mine’s workforce strategy aligns with its broader digitisation strategy. It is also evident that as operations shift from manual to digital and automated systems,

workforce composition is reassessed to ensure skill development, task allocation, and talent retention strategies support long-term sustainability.

The workforce restructuring process follows the 80–20 Pareto principle, taking precedence over operational functions. This is affirmed by the interview informants, who stated that the workforce planning of the mine placed emphasis on roles and functions exerting significant impact on operational success. According to the mine 2018-2022 Social and Labour Plan, the roles consist of two preaggregation groups: (i) Senior management and operations management, professionally qualified and experienced specialists and mid management (also called critical core skills) (ii) Skilled technical and academically qualified workers, junior management, supervisors, foremen and superintendents (also called core skills). Each of the groups represents hard to fill positions, all factoring into the Pareto principle that a select few key roles are responsible for the majority of productivity and efficiency. The classic mining crew layers are such as production, security, technical and administration. However, the industry is shifting towards more tech-based roles structure, through the combination of HCPS as well as digital automation.



Figure 4.15: Alignment of business strategy and people strategy.
Source: Adapted from The company (2018)

Furthermore, based on their annual reports the mine's workforce strategy adheres to the first principle of the Strategic workforce framework, which stipulates that the mine's workforce strategy must align with organisation's strategic objectives. The mine executes this strategy by integrating key people management elements such as performance management, talent management, total rewards, and learning and development, see figure 4.15 for its illustration.

(a) Workforce Optimisation and short term workforce management

KIR4 outlined that, in response to evolving operational demands and the need to reassign tasks among current permanent staff, the mine has implemented a flexible and adaptive workforce strategy. This includes a combination of full-time, contract, and remote employment models aimed at enhancing agility and efficiency. KIR4 elaborated as follows:

"Dynamic Task Reassignment

Critical tasks that arise due to automation or operational changes are identified and reassigned in a structured manner.

- Employees are matched to emerging roles based on their skill sets—for example, a technician previously focused on mechanical maintenance may transition into monitoring or operating automated equipment.
- Cross-functional teams are formed to ensure coverage of critical areas during times of change or increased operational demand.

Real-Time Scheduling Systems

Workforce management software plays a central role in facilitating real-time scheduling and task reallocation.

- The system allows for rapid adjustment of shift patterns to ensure sufficient coverage for high-priority operations, especially during transitional phases.
- It also enables the ongoing monitoring of task completion and employee feedback, which informs the continuous refinement of schedules and resource allocation."

This approach, as described by KIR4, supports short-term workforce agility and lays the groundwork for a responsive, modernised mining operation.

(b) Long-Term Workforce Adaptability

Findings from KIR3 revealed that the transformation of the mining workforce since 2018 is underpinned by strategic interventions aimed at enhancing adaptability, optimising task allocation, and fostering long-term sustainability. As the mining industry continues to

modernise, the integration of human-cyber physical systems (HCPS), automation, and digital technologies necessitates a structured approach to workforce planning. The mine's long-term workforce strategy incorporates three key pillars: comprehensive skills development, talent retention and inclusion, and technology-driven workforce management. These strategies are evident measures, designed to ensure that the workforce remains responsive to evolving technological demands while maintaining operational efficiency and stability. In answering the question, "*Could you please provide insights into the company's long-term strategic approach to planning the workforce structure and determining the number and qualifications of the workforce*? KIR3 responded as follows,

"Alignment with Strategic Goals

- *Our workforce planning is closely aligned with the company's goals for increased automation, sustainability, and profitability.*

- *Anticipating future technological, regulatory, and market trends to shape the workforce structure.*

Skills and Qualifications Mapping

- *Conducting skills audits to identify gaps in existing competencies.*

- *Mapping skills required for roles like automation specialists, data scientists, and sustainability officers.*

- *Emphasising the need for employees with cross-functional expertise (e.g., combining mining knowledge with IT or AI skills).*

Workforce Structure and Numbers

- *Incorporating a mix of full-time, contract, and remote workers to adapt to dynamic operational needs.*
- *Preparing the next generation of leaders by identifying and nurturing talent."*

***(c)* Talent Retention and Inclusion**

After establishing that the company has the next generation of leaders in its sights and a strategy to prepare them, this study also examined talent retention. Interviews revealed that with the

changing complexity of the mine's workforce, driven by automation and digitisation, the site needs to meet the dual challenge of keeping hard won expertise while creating a more inclusive environment. The Article compares the positive effects mentioned in Section 4.3 above of technology adoption on increasing inclusion in the workforce, especially for those whose careers were limited by physical impairments. But this is just one part of the overall retention strategy. The mine has implemented structured, clear career development pathways that maintain critical experience for the long term and align people's growth with their desires and the operational needs of the company as it continually adapts.

Annual reports from 2018 to 2023 support the Social and Labour Plan's assertion that leadership development remains a core focus, aimed at equipping employees with the skills needed to navigate an increasingly complex mining landscape. KIR3 reinforced this, emphasising that the mine views leadership investment as a strategic priority, explaining, "Preparing the next generation of leaders by identifying and nurturing talent." This approach aligns with the mine's broader workforce strategy, where talent retention and inclusion are central themes, further underscoring its long-term commitment to human capital development.

"*Talent Pool Assessment*

- *Maintain an up-to-date database of our employees' skills, certifications, and experiences.*
- *Leverage historical performance records to identify employees who excel in specific tasks.*
- *Define the skills, knowledge, and physical requirements for each task to match them to suitable employees*."

(d) Technology-Driven Workforce Management

Findings from the interviews indicate that the mine regards the integration of technology into workforce planning and management as essential for optimising task allocation and enhancing operational flexibility. To this end, the mine has implemented real time scheduling systems and task reallocation software, enabling dynamic workforce adjustments in response to evolving operational demands. These technological advancements enhance efficiency by ensuring that employees are assigned roles that align with their skills and competencies in real-time, thereby maximising productivity while maintaining workforce adaptability. Recognising the significance of short-term workforce planning in this context, the study posed the question,

"*How does short-term employee retask planning prioritize the assignment of individuals based on existing abilities while incorporating priority rules that account for logistical, financial, and ergonomic considerations in shaping the talent pool?"* In response, Key Interview KIR 2 and 3 provided the following insights:

"Talent Pool Assessment

- *Maintain an up-to-date database of our employees' skills, certifications, and experiences.*
- *Leverage historical performance records to identify employees who excel in specific tasks.*
- *Define the skills, knowledge, and physical requirements for each task to match them to suitable employees.*

Logistical Goals:

- *Assign employees based on proximity to the task location to reduce travel time and improve efficiency.*
- *Optimize team compositions to ensure critical operations are covered without disrupting workflows.*

Financial Goals:

- *Prioritise employees already on-site to minimize overtime or additional hiring costs. - Use available talent to prevent expensive downtime for machinery or systems.*

Ergonomic Goals:

- *Avoid assigning physically demanding tasks to employees prone to injury or fatigue. - Rotate tasks to balance workload and reduce strain on specific individuals.*

Task Matching Process

- *Use workforce management software with algorithms to suggest task assignments based on predefined criteria (skills, availability, and location).*
- *Supervisors review and approve assignments to ensure alignment with broader operational goals.*

Establishing the Talent Pool

- *Encourage employees to acquire secondary skills, expanding the available talent pool for diverse tasks.*
- *Identify and maintain a group of versatile employees capable of stepping into high-priority roles when needed.*
- *Categorize employees into tiers based on their proficiency and readiness for task reassignment."*

(e) Training, Upskilling, and Workforce Adaptability

Building on Bruecker et al.'s (2015) assertion that strategic workforce planning requires continuous skills assessments to ensure competency alignment, the study finds that the mine employs pre-assessments as a key tool for identifying skill gaps, while targeted training programmes support long-term workforce adaptability. Interviews reveal that these initiatives are designed to bridge gaps in expertise and prepare employees for the demands of an evolving mining landscape. According to key KIR 3, the mine's skills development strategy focuses on:

(ei) *Cross-functional skill development* - Integrating traditional mining expertise with IT and digital competencies.

(eii) *Immersive learning techniques* - Utilizing digital training modules and simulation based learning to enhance practical understanding.

(eiii) *Reskilling and upskilling initiatives* - Enhancing literacy, providing technical training, and developing executive capabilities.

When asked about existing processes for skill assessments and competency evaluations to determine workforce readiness for modernisation, KIR 3 explained:

"As the organization evolves, emerging skills are determined by shifts in work methods and technological advancements in mining. Skills are aligned with operational needs, and new recruits undergo pre-assessments to ensure they meet business requirements. Continuous evaluations identify hard-to-fill vacancies, which are incorporated into a scarce skills analysis. This analysis informs workforce planning, leading to targeted interventions aimed at closing skill gaps."

(f) Comprehensive Skills Development

Developing Talent for the Future Digital Mine A key tenet of the mine's long-term workforce strategy is to continuously upgrade the skillset of our employees to match the digitalization of the mining operation. These training programmes have matured to effectively blend immersive learning methodologies with traditional mining knowledge and advanced digital and automation-related competencies. These programs stress the need for digital literacy at every level of the workforce, with expertise in semi-autonomous drill programming, IoT-based maintenance and AI-supported decision-making.

Understanding the challenges that come with digital transformation, the mine employs customized training and job reassignment methods to help employees struggling to learn new technologies. Instead of letting technological changes only exclude parts of the workforce, specific upskilling opportunities are offered so that workers have the skills needed to compete in a re-engineered industry. The mine also promotes a culture of learning through structured training initiatives and mentorship programmes. The Social and Labour Plan (SLP) outlines structured skills development initiatives, including:

(fi) *Adult Education and Training (AET)* - Enhancing foundational skills to ensure workforce adaptability.

(fii) *Learnerships and Apprenticeships* - Providing hands-on experience and industry specific qualifications.

(fiii) *Scholarships and Internships* - Supporting the next generation of industry professionals.

These targeted training initiatives align with the requirements of the amended Mining Charter, reinforcing the mine's commitment to professional development and long-term workforce sustainability in an increasingly technology-driven mining environment.

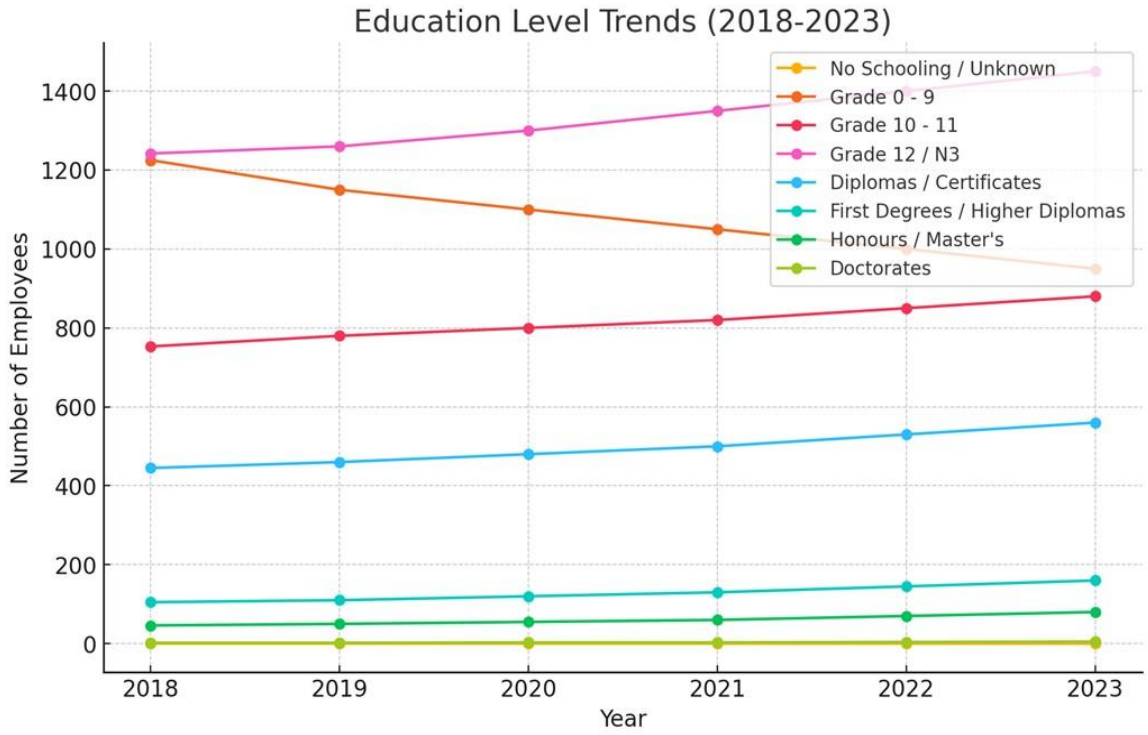


Figure 4.16: Training impact on education level
Source: Author's own work

Findings from 2018–2023, illustrated in figure 4.12, demonstrate that higher education levels (Honours, Doctorates) benefited most from training programmes, while lower education levels (Grade 0–9) experienced slower improvement rates. Figure 4.15, the Education Level Trends (2018-2023) chart, illustrates the evolution of different qualification levels and their contribution to upskilling. Supported by both SLP content and interview responses, the evidence suggests that continuous training has proven critical in reducing human error and enhancing operational efficiency. Figure 4.7 is an illustration of the Education Level Trends (2018-2023) chart. It shows how different qualification levels evolved contributed to upskilling.

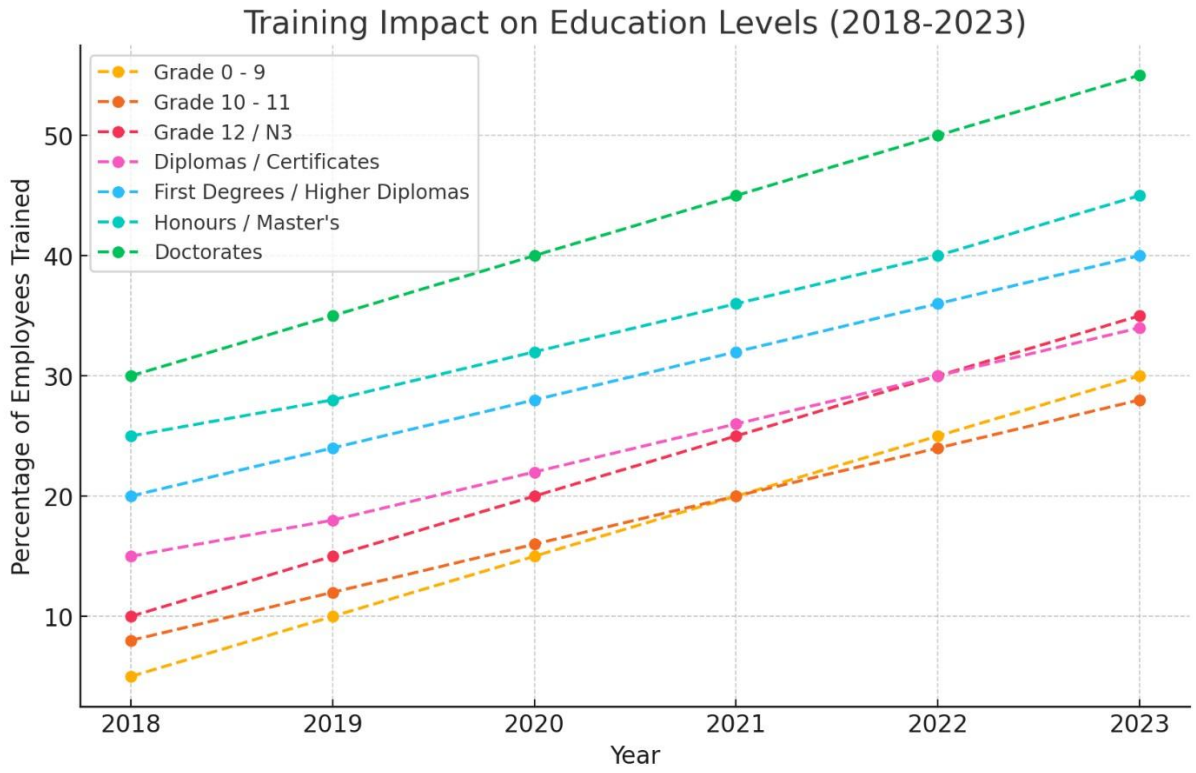


Figure 4.17: Education Level trends
Source: Author's own work

4.4.4 Summary of findings

The findings of this study illustrate how modernisation initiatives have fundamentally reshaped workforce dynamics, safety protocols, productivity levels, and overall operational efficiency. Although initial hurdles, such as workforce resistance and critical skill shortages, posed challenges to implementation, targeted interventions in training, organisational culture, and stakeholder engagement played a crucial role in navigating these complexities. A historical review of the mine's modernisation efforts highlights the necessity of synchronising human capital development with technological innovation. By placing workforce transformation at the centre of its digital integration strategy, the mine has not only facilitated a smoother transition but also established a viable framework for sustainable modernisation within the gold mining sector.

Objective	Key Findings
Objective 1	Modernisation is shaped by policy pressures, economic necessity, and labour tensions. While regulatory frameworks exist, they are inconsistently applied, and often disconnected from operational realities.
Objective 2	Technological deployment is selective and uneven but is reshaping job profiles significantly. The workforce is polarised between adaptable and displaced groups, with training mechanisms proving inadequate.
Objective 3	Workforce planning remains largely reactive. Although some decentralised, tech-enabled task models are emerging, the lack of integrated long-term talent planning threatens sustainability.
Cross-Cutting Issue	Health and safety are a key justification for tech adoption but is inconsistently integrated into planning frameworks. Mines with strong safety cultures tend to lead in modernisation.
Cross-Cutting Issue	Value creation from modernisation remains narrowly defined. Long-term social, community, and environmental returns are not embedded in current strategic planning.

CHAPTER FIVE

ANALYSIS AND DISCUSSION

5.1 Introduction

This chapter presents an analysis and discussion of the study's findings, focusing on how the adoption of people-centric 5IR modernisation technologies is reshaping workforce dynamics in the mining sector. Using the mine under study as a case, the chapter contextualises South Africa's broader transition towards a 5IR workforce and examines the implications of digital transformation for health and safety, employment structures, skills development, and operational efficiency. It offers an analytical synthesis of the data presented in Chapter 4, structured around key thematic categories. The analysis is framed within the conceptual context of the Fourth and Fifth Industrial Revolutions, particularly as they relate to mining-sector transformation. Key areas of focus include how modernisation has unfolded, who has been affected, why these effects matter, and how existing literature contributes to understanding these dynamics. These discussions are anchored in the paradigms of human capital development, workforce planning, and policy, aligned with South Africa's socio-economic development trajectory.

5.2 Policy, Economic, and Labour Factors Influencing Modernisation

(a) Economic Drivers and Operational Necessity

The data indicate that the dominant catalyst for modernisation in the studied mining context has been economic necessity. Rising input costs, inefficiencies tied to ageing infrastructure, and the need for global competitiveness drove company leadership to prioritise mechanisation and digitalisation. In the early phases, automation efforts focused on cost-containment rather than innovation. Technological change was a reactive survival strategy rather than a proactively planned evolution.

(b) Labour Disruption and Institutional Strain

This reactive modernisation disrupted the workforce profoundly. Over 1,500 roles were lost—ranging from underground miners to contract workers—causing labour tensions, industrial action, and declining morale. The restructuring fractured organisational trust and destabilised

relationships with unions. Early decisions around severance and redeployment were made with limited strategic foresight into long-term human capital impacts.

(c) Policy Vacuum

The absence of a supportive or guiding policy framework compounded the situation. Unlike other sectors undergoing technological transition with active state involvement, mining modernisation in this case study occurred in a regulatory vacuum. No governmental upskilling interventions, compensation strategies, or collaborative governance platforms were observed. Although there was no deliberate resistance from the state, the absence of support mechanisms left the company and workers exposed to unmanaged socio-economic risks.

5.3 The Most Affected and Involved Stakeholders

(a) Negatively Affected Groups

The findings highlight that operational-level employees bore the brunt of the transition. Underground workers, machine operators, and support service contractors were the most negatively impacted, with many roles rendered obsolete. Unionised labour, often aligned with these categories, experienced disempowerment and frustration due to their exclusion from planning processes.

(b) Key Drivers of Change

Change was driven largely by senior executives, operations directors, and technical experts focused on operational optimisation. Human Resources personnel played reactive roles, managing redundancies and transition logistics, but lacked a systemic framework to anticipate or mitigate impacts. Technology professionals gained institutional authority, becoming central actors in the design and implementation of new operational systems.

(c) Interpretative Insight

The polarisation between winners and losers in the transition process underscores an uneven distribution of agency, resources, and outcomes. While some roles expanded in scope and value, others were eliminated or downgraded. The absence of participatory processes and inclusive foresight planning exacerbated these disparities.

5.4 The Strategic Risk of Unbalanced Modernisation

The consequences of technologically driven change without commensurate investment in human capital transformation are severe. Productivity gains from automation can be undermined by skills mismatches, morale collapse, and social instability. Moreover, the erosion of a company's social license to operate becomes a tangible risk when communities perceive that technological progress benefits the few at the expense of the many. The findings reinforce the view that successful modernisation is not solely technical, it is social, ethical, and strategic. Long-term viability demands a co-evolution of people and systems. Organisations must shift from technology-centred transformation to people-integrated transformation, where workforce planning is embedded from the outset.

5.5 Literature Explaining the Tensions

The analytical insights of this study align with three core scholarly positions:

Theme	Reference	Key Contribution
Contextualised Tech Frameworks	Jacobs & Webber-Youngman (2017)	Argue for mine-specific, policy-backed modernisation frameworks
Tech-Human Integration	Kagermann et al. (2013)	Advocate for strategic alignment of automation and workforce planning
Upskilling in Digital Transition	Academy to Innovate (2024)	Stress real-time training as a pillar of successful digital workforce evolution

These literatures affirm the need for mining sector transformation strategies that are not only economically and technologically viable, but socially responsive and contextually grounded.

5.6 Workforce Transition Strategies in Practice

(a) Future Skills and Competencies

The study reveals that there is a growing demand for skills in automation operation, cybersecurity, data analytics, AI, and remote-control systems. In parallel, soft skills such as systems thinking and interdisciplinary fluency are rising in importance.

(b) Training and Capacity Development

Training strategies observed included blended learning (digital and hands-on), virtual reality simulations, and personalised upskilling pathways. Lifelong learning frameworks are beginning to emerge as standard practice.

(c) Talent Planning and Redeployment

Organisational talent strategies incorporated both external hiring and internal reskilling. Skills audits and job redesigns enabled partial mitigation of workforce disruptions. Ergonomic planning and transparent communication were identified as key success factors.

(d) Technology and Safety Enhancements

Automation of hazardous tasks, predictive maintenance, and real-time monitoring improved occupational safety. Technology also allowed greater workforce inclusivity by enabling roles for physically limited workers.

(e) Retention, Inclusion, and Change Management

Balanced job design, peer mentorship, and alternate career pathways were used to retain institutional knowledge. Change management strategies focused on early stakeholder engagement, immersive upskilling, and cultural adaptation to new performance metrics.

5.7 Operator 4.0 and the Exclusionary Edge of Modernisation

The evolution of the mining workforce in the context of digitalisation is aptly captured through the Operator 4.0 paradigm, which represents a confluence of human-machine collaboration, cyber-physical systems, and real-time data-driven optimisation. This study confirms that the mining industry has moved beyond the rudimentary automation of Operator 3.0, characterised by mechanised tasks performed under human supervision, and is now progressing rapidly into the Operator 4.0 phase, where technological integration has become both intelligent and autonomous.

The empirical findings reflect various Operator 4.0 roles already manifesting within the South African mining sector:

i. The Analytical Operator, who utilises advanced data analytics to improve decision-making.
ii. The Augmented Operator, supported by virtual and augmented reality tools.
iii. The Healthy Operator, whose performance and wellbeing are monitored through biometric data.
iv. The Smart Operator, interacting with intelligent machines and predictive systems; and
v. The Social Operator, enabled by mobile, networked systems to collaborate across digitally synchronised environments.

Together, these roles suggest a future workforce that is increasingly digitally empowered, remotely enabled, and less physically embedded in the traditional mining environment. These roles also signal a deep structural shift in how work is defined, measured, and performed in mining, with profound implications for organisational design, productivity, and health and safety outcomes.

However, this technological transformation is not universally inclusive. The study identifies a critical oversight in the contemporary discourse on digital transition, the systematic exclusion of a segment of the workforce that lacks the foundational skills necessary for upskilling or digital participation. Termed "Worker X" in this research, this category encompasses individuals predominantly holding General Education and Training (GET) level qualifications, those who have not progressed beyond Grade 9 or ABET Level 3, and in some cases, never attended formal schooling.

The emergence of Worker X reflects the exclusionary edge of modernisation—where the same systems that optimise efficiency and profitability inadvertently marginalise those unable to integrate into the new digital order. This segment faces an acute risk of redundancy, often without viable alternative employment pathways. Evidence from the study further suggests that some displaced individuals are pushed toward informal and illegal mining operations, which remain physically accessible but are fraught with health, safety, and legal risks.

This exclusion is not merely a technical or training issue; it is a structural blind spot in the current implementation of Fourth and Fifth Industrial Revolution principles in South African mining. Without intervention, the displacement of Worker X will likely exacerbate:

i. Rural poverty and social fragmentation, especially in areas dependent on mining for livelihood;
ii. Unregulated informal economies, including illegal mining syndicates;
iii. Community disillusionment and resistance, which may undermine the social license to operate.

Therefore, it is imperative to reframe inclusivity in digital transitions not only in terms of who can be trained but also who cannot and what becomes of them. This opens an urgent policy window for mining firms, labour unions, and the state to consider interventions such as:

i. Sheltered employment models, creating dignified work outside the high-tech mining stream;
ii. Transitional safety nets, including extended retraining timeframes and social protection;
iii. Community-based micro-enterprise development, absorbing displaced workers into supported local economies.

Recognising Worker X as a distinct category is essential for a just and sustainable mining future. It disrupts the assumption that all workers can or will be reskilled and challenges the sector to design dual-path transformation strategies: one that embraces innovation, and another that mitigates exclusion. Further research should follow the trajectory of Worker X to understand the long-term economic, social, and psychological effects of digital-era displacement, and to model inclusive futures that leave no worker behind.

5.8 Legislative Gaps in Managing Technological Transitions

This study identifies a critical legislative gap in South Africa's mining modernisation landscape: the absence of a coordinated, enforceable regulatory framework to manage the socio-economic impacts of technological transformation, particularly as it relates to labour displacement, upskilling, and stakeholder engagement.

5.8.1 Key Dimensions of the Legislative Gap

i. No Framework for Technological Transition Management: There is no policy that mandates or guides how mines should transition from labour-intensive to automated operations in a way that protects workers. The study found no evidence of national or provincial regulations

offering structured support for retraining, redeployment, or social cushioning during automation-driven retrenchments.

ii. Lack of Skills Development Integration in Mining Policy: Although national skills development strategies exist (e.g., NSDP), they are not specifically integrated into mining legislation or enforced through sector-specific compliance measures (e.g., the MPRDA or Mining Charter). Upskilling and reskilling were handled internally and reactively by the company, not in response to any legislative requirement.

(iii) No Legal Mandate for Proactive Stakeholder Engagement in Tech Rollout: The retrenchment of the over 1,500 employees occurred with little indication of pre-emptive legislative protections for labour unions or community stakeholders in the digital transition process. Labour unrest and industrial disruptions point to poorly regulated change management, rather than collaborative or legally guided modernisation**.**

(iv) Missing Policy Instruments for the Fifth Industrial Revolution (5IR): Current mining and labour regulations remain geared towards 3IR or early 4IR conditions, lacking language and frameworks for AI integration, remote operations, robotics, or digital mine workforces. There is no forward-looking legislation that anticipates or prepares for the structural workforce changes emerging from 5IR technologies**.**

While economic and technological forces are advancing rapidly, South African legislation has not kept pace with the realities of digital transformation in mining. The result is a policy vacuum in which companies proceed with modernisation out of necessity, while workers face displacement and uncertainty with no enforceable safety nets, skills transition pathways, or structured mediation mechanisms.

5.9 Evolution of Digital Transformation in Mining: A Heatmap Review

Having synthesised the findings of the study, this heat map presents a longitudinal review of modernisation progress across key operational and human capital dimensions over the study period. Progress levels range from 1 (initial stage) to 5 (maturity/optimisation), capturing the gradual transformation of the mining organisation across 14 interrelated categories.

The visual highlights a significant inflection point around 2019, where most categories transitioned from early stages (levels 1–2) to accelerated implementation (levels 3- 4),

particularly in workforce productivity, innovation for safety, and cost optimisation. By 2022–2024, the majority of categories reached peak levels (4–5), suggesting an advanced stage of integration in both technical and organisational terms. Of particular interest:

i. Human Capital Effects, Workforce Planning, and People Capacity improved only after 2020, reinforcing the study's finding that human-centred strategies lagged technical implementation.

ii. Organisational Culture and New Ways of Working saw steep improvements from 2020 onwards, reflecting the shift toward more agile, digitally enabled work models.

iii. Reducing the Workforce and Fleet Size show steady upward movement, aligning with automation goals but also underscoring the exclusionary patterns discussed in Section 5.7 (Operator 4.0 and Worker X).

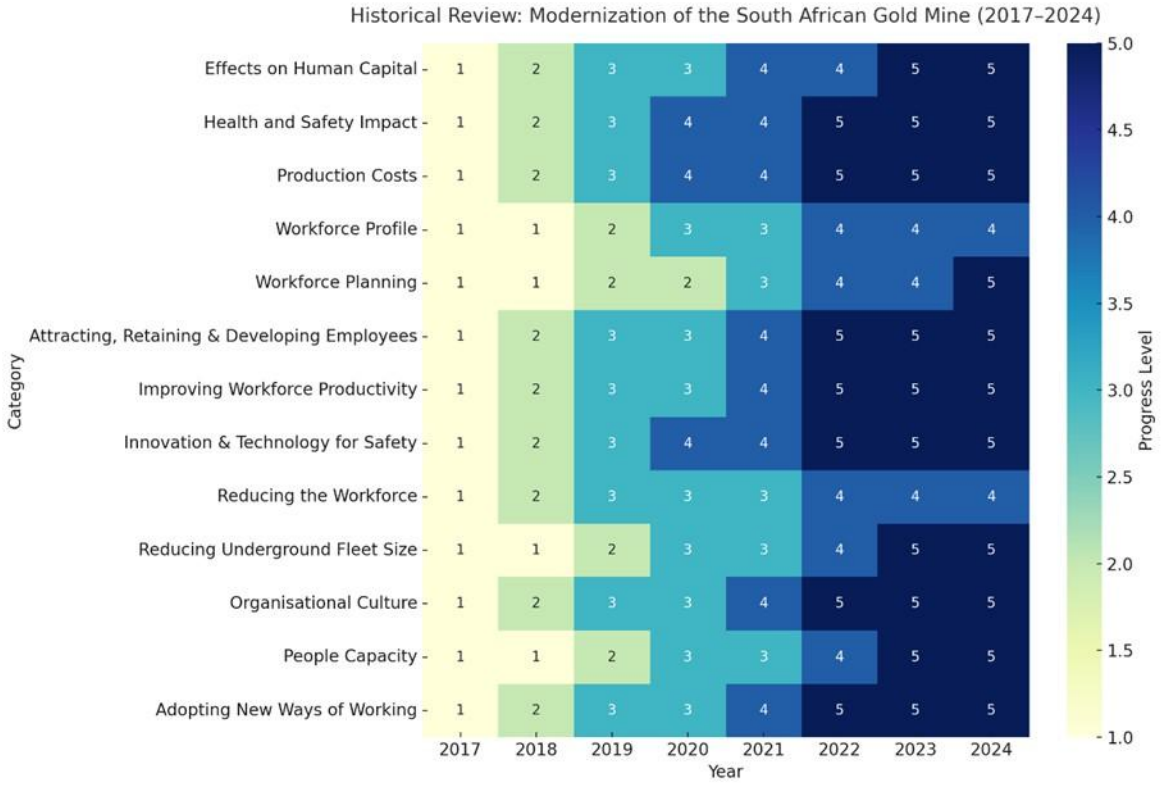


Figure 5.2: Heatmap of the historic review of the modernisation journey (2017-2024) *mining organisation across 14 interrelated categories.*
Source: Author's own work

This chapter has provided a comprehensive analytical account of the empirical findings. The chapter emphasised that while technological transformation in the mining industry is operationally imperative, it remains socially incomplete. Without integrated strategies for

workforce adaptation, policy support, and inclusive innovation, the benefits of digitalisation may be accompanied by intensified exclusion, particularly of Worker X. The discussion frames the next chapter, which will consolidate these findings into actionable conclusions and forward-looking recommendations.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter summarises the main findings of the research. It states the key findings to confirm that the research questions given in chapter one has been answered. The chapter also offers recommendations for different aspects of the research. Lastly, it discusses the limitations of the study while highlighting areas for future study regarding the missing worker, policy and the possible ripple effects of modernisation to the economy, society and environment at large.

6.2 Overall Key Findings of the Research

This study set out to examine how the adoption of people centric Fifth Industrial Revolution (5IR) technologies is reshaping workforce dynamics in South Africa's mining sector. Using a single mining operation as a case study, the research explored the multidimensional impact of digital modernisation on employment structures, skills requirements, health and safety practices, and organisational culture. True to the assertions of Atwell (2017) and Humayun (2021), the study finds that indeed the 5IR is reshaping business landscapes. Gügerçin and Gügerçin (2021) predicted its full realisation by 2025, and the findings of this study affirm that 5IR-based modernisation has already become a practical reality.

The findings demonstrate that modernisation is progressing unevenly, with advanced technology integration often outpacing human capital development. While productivity gains and safety improvements have been recorded, the benefits are not equitably distributed. A central insight of the study is that the workforce is undergoing a fundamental transformation through the Operator 4.0 paradigm, which encompasses roles such as the analytical, augmented, healthy, smarter, and social operator. However, the study also introduces the concept of "Worker X," referring to a marginalised group of workers, primarily low-skilled or underqualified individuals, who are excluded from the modernisation trajectory. These workers face a heightened risk of displacement and socio-economic marginalisation, including a greater likelihood of turning to illegal mining.

The heatmap presented in Chapter 5 illustrates the longitudinal progression of modernisation efforts from 2017 to 2024. It shows that technical innovations advanced significantly earlier

than human capital initiatives, highlighting a reactive rather than anticipatory approach to workforce planning. The study's thematic analysis further uncovered tensions between policy ambitions and practical implementation, particularly around inclusivity, skills development, and social safety nets.

6.2 Theoretical and Practical Contributions

Theoretically, the study builds on and extends the Operator 4.0 framework by introducing Worker X, a novel conceptual category that draws attention to the exclusionary edge of digital modernisation. This represents a key contribution to scholarship on 4IR and 5IR workforce transformation, particularly in resource-intensive sectors such as mining.

Practically, the research offers a grounded, empirical account of how modernisation is unfolding in real-time within a South African context. The use of a heatmap to track change over time provides a methodological tool for similar future studies. The thematic findings offer actionable insights into the areas where mining organisations, policymakers, and labour unions need to focus their attention. b

6.3 Conclusions

Modernisation in mining is not simply a technical or economic phenomenon, it is a deeply human process with profound implications for social equity, employment sustainability, and organisational culture. This study concludes that a successful 5IR transition depends not only on technological readiness but also on proactive human capital development, inclusive workforce planning, and policy coherence.

6.4 Recommendations

Drawing from the insights generated in this study, a series of recommendations are proposed to guide industry stakeholders, policymakers, civil society actors, and future researchers in facilitating a more inclusive and strategic transition into the 5IR mining landscape.

For industry leaders, it is imperative to develop digital transformation strategies that are explicitly inclusive of low-skilled and underqualified workers. The study has shown that while technological advances such as those encapsulated in the Operator 4.0 paradigm offer considerable efficiencies, they risk marginalising segments of the workforce that lack formal

education or digital skills. To address this, anticipatory workforce planning should be adopted, ensuring that skills development initiatives are aligned with technological trajectories well in advance of implementation. Moreover, the adoption of human-centred design principles in deploying Operator 4.0 technologies can help mitigate exclusionary outcomes by embedding worker needs and ergonomic considerations into the technological ecosystem. In addition, institutionalising robust change management processes that promote digital fluency and cultural agility across all levels of the organisation will support a smoother, more equitable transition into modernised mining operations.

Policymakers also have a critical role to play. It is recommended that national upskilling and reskilling policies be formulated, with a particular focus on workers who are GET-qualified or operating at ABET levels. These categories have been identified as most vulnerable to displacement and marginalisation within the modernisation process. To prevent deepening social inequality, the state should introduce comprehensive social protection mechanisms, offering transitional support to displaced workers and creating viable pathways into new forms of employment or entrepreneurship. Public-private partnerships must also be strengthened to scale up digital inclusion initiatives, particularly in mining-affected communities. Furthermore, there is a need for systematic monitoring and evaluation of the social impacts of mining modernisation, to ensure that policy responses remain grounded in evidence and responsive to the evolving socio-economic terrain.

Labour unions and civil society organisations must advocate more assertively for just transition frameworks that include marginalised categories such as the Worker X cohort identified in this study. By bringing this often-overlooked group into the centre of negotiations and strategic planning, social actors can help safeguard livelihoods and promote equity. Awareness campaigns aimed at educating workers and communities on both the risks and the opportunities of 5IR-driven modernisation are also essential in creating informed constituencies that can engage constructively with technological change. In addition, partnerships with educational institutions and mining houses should be cultivated to co-design training programmes that are contextually appropriate, accessible, and responsive to future skills requirements.

Finally, the academic community is encouraged to build on this research through longitudinal studies that trace the long-term career trajectories of Worker X individuals. Such studies could provide critical data on the cumulative effects of exclusion from formal mining employment, potentially shaping future interventions. Further investigation is also needed into the broader social and economic ripple effects of workforce exclusion, especially in mining-dependent regions. Comparative research across different mining operations and sectors would yield

valuable insights into how modernisation unfolds under varying regulatory, technological, and socio-political conditions, thereby enriching the global discourse on inclusive digital transformation.

These recommendations, though distinct by audience, converge around a common imperative: to ensure that the transition toward smart, automated, and human-centric mining does not reproduce or deepen existing inequalities. Instead, with foresight, collaboration, and targeted investment, it can catalyse a new era of equitable and sustainable growth within the mining sector and beyond.

Additionally, this study utilised the 2018–2022 Social and Labour Plan (SLP) as its primary empirical source for workforce demographic data, as neither preceding nor subsequent iterations were publicly accessible at the time of research. A longitudinal design would enable tracking of modernisation impacts over an extended period, particularly in relation to Worker macroeconomic implications of technological exclusion.

In conclusion, this study has highlighted the urgent need for mining stakeholders to approach modernisation with a lens of inclusivity, foresight, and social responsibility. As South Africa moves further into the 5IR era, the mining sector must serve as a model for how technology and humanity can progress together.

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APPENDIX A

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Research Office

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

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H24/01/30**
PROJECT TITLE	The impacts of the fifth industrial revolution on employment in the gold mining sector in South Africa
INVESTIGATOR(S)	Ms C Sihlali
SCHOOL/DEPARTMENT	School of Geography, Archaeology and Environmental Studies/
DATE CONSIDERED	26 January 2024
DECISION OF THE COMMITTEE	Approved Risk Level: Minimal
EXPIRY DATE	23 June 2027

DATE 24 June 2024 **CHAIRPERSON** _____
(Professor J Watermeyer)

cc: Supervisor : Professor M Simatele

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **A SIGNED COPY** returned to the Secretary electronically. 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 be contemplated from the research procedure as approved I/we undertake to submit an amendment of the protocol to the Committee. **I/we agree to completion of a regular progress report. For Minimal and Low Risk studies, this is due annually on 31 December. For Medium and High Risk studies, this is due twice annually on 30 June and 31 December.**

_____ _____/_____/_____
Signature **Date**

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

APPENDIX B

UNIVERSITY OF THE WITWATERSRAND
FACULTY OF SCIENCE
School of Geography, Archaeology and Environmental Studies

Good day

My name is Cebisa Sihlali. I am a Masters student at the University of the Witwatersrand, Johannesburg. My supervisor is Prof. Mulala Simatele. I am conducting a research study focused on gaining insights into how emerging 5IR technologies, such as Human Cyber Physical Systems are anticipated to impact various aspects of the gold mining sector, particularly its workforce.
The study title is, A fifth industrial revolution, human capital-based matrix for the gold mining sector in South Africa.

As part of this research, I wish to interview senior managers in mining companies who are responsible for modernisation, technology and human resources in order to better understand how emerging 5IR technologies are anticipated to impact various aspects of the gold mining sector, particularly its workforce. I am, therefore, writing to extend an invitation to you to share information with me regarding the above-mentioned topic, in respect to your mining operations, by answering some interview questions that I have prepared. The interview is proposed to take place in person at your offices or online, at a time suitable to yourself.

With your permission, I would like to audio record the interview and take notes. The key informant interview should take approximately 60 minutes to complete. There is no envisaged risk involved in participating in this study. All information you share will be kept confidential. This data will be stored in a password protected computer. Only the researcher will have access to the data. The interview will be confidential and anonymous. When I share the results of the research study, I will not include your name or anything else that could identify you. With your permission, other researchers may use the data collected from this research study, but your name and any personal information will not be used or passed on.

If you decide to take part in the research study, it should be because you want to volunteer. You do not have to take part. You can stop being in the study at any time. You do not have to answer any questions if you do not want to. You will not get any direct benefits if you choose to join the research study. You will not lose any services, benefits or rights you would normally have if you decided not to join. Taking part in the research study will not cost you anything. You will not be paid for being in this research study.

This research study will be written up as a research report. The report will be available on the university library website. If you would like to receive a summary of this report, I will be happy to send it to you.

If you have any questions during or afterwards about this research study, feel free to contact me or my supervisor on the details listed below. If you have any concerns or complaints about the ethical procedures of this research study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za.

Yours sincerely,
Cebisa Sihlali

Researcher:
Cebisa Nandipa Sihlali, 815585@students.wits.ac.za, 072 1919300

Supervisor:
Prof Mulala Simatele, mulala.simatele@wits.ac.za (011) 7176602

APPENDIX C

Consent Form

Title of project
The impacts of the fifth industrial revolution on employment in the gold mining sector in South Africa

Name of researcher
Cebisa Nandipa Sihlali

I, ……., agree to participate in this research project.

I agree to the following:

(Please circle the relevant options below)

The research study was explained to me. I understand what this study is about.	YES	NO
I understand that my participation is voluntary and that I can withdraw at any time.	YES	NO
I agree that the interview may be audio recorded	YES	NO
I agree that direct quotations from my interview activity may be used by the researcher in their research report, but that they will not be attributed to me	YES	NO
I agree that my participation will remain anonymous (my name or other identifying data will not be used by the researcher in their research report	YES	NO
I agree that other researchers may use the information I provide in my interview	YES	NO

…… (signature)
…… (name of participant)
…… (date)

,,,

APPENDIX D

INTERVIEW SCHEDULE

THE IMPACTS OF THE FIFTH INDUSTRIAL REVOLUTION ON EMPLOYMENT IN THE GOLD MINING SECTOR IN SOUTH AFRICA

Successful Application Of Technologies Centred Around People (SATCAP)

(The researcher wants to understand how emerging technologies will affect the current and future workforce in gold mines, amidst the emergence of the fifth industrial revolution)

Semi-Structured, In-Depth Interviews with Senior Staff Involved in Workforce Management at Mine under study's Operations and Leading the Adoption of 5IR Technologies

Thank you for taking the time to participate in this study. Please note that your participation is completely voluntary, and you can withdraw at any time without consequences.

Objective:

(The researcher wants to understand how emerging technologies will affect the current and future workforce in gold mines, amidst the emergence of the fifth industrial revolution)

The researcher will make use of the probes provided to guide the Interviewee.

---

1. **Key Objectives and Triggers:**

   ?What are the key objectives or main triggers driving the mine's modernisation initiative?

   The key objectives and triggers driving mine's modernization initiative include:

   Response provided by Key Interview Respondent 7 (KIR7)

   - Health and Safety Improvements
     - Enhanced Safety Measures: Leveraging technology to achieve the highest safety standards, including deploying Collision Avoidance Level 9 systems to minimize accidents.
     - Compliance with Regulations: Meeting Department of Mineral Resources and Energy (DMRE) requirements and addressing gaps in past implementations, such as CAS Level 9 systems.

   - Operational Efficiency

- Increased Productivity: Optimizing processes through automation, integrated systems, and tele-remote operations to maximize output while reducing downtime.
- -Cost Reduction: Streamlining operations and reducing energy, labor, and equipment maintenance costs through advanced digital solutions.

- Digital Transformation and Modernization
  - Real-time Data Utilization: Building an Operations Control Centre and upgrading underground networks to enable seamless data collection, monitoring, and decision-making.
  - Integrated Platforms: Establishing connected systems and databases for better process alignment across the value chain.

- Workforce Development
  - Skills Development: Preparing the workforce for future demands through immersive training, VR simulations, and exposure to new technologies.
  - Cultural Change: Implementing change management strategies to support employee buy-in and adaptation to new technologies.

- Resilience and Competitiveness
  - Future-Proofing Operations: Ensuring the mine remains sustainable and competitive in a rapidly changing mining industry.
  - Stakeholder Value Creation: Demonstrating value to stakeholders through improved efficiency, safety, and environmental responsibility.

2. Technology Implementation Strategy:

? In 2022, Johan Sliep mentioned that your deployment of technology execution strategy, which commenced in 2019, comprises 3 horizons: “1) Planning, scheduling, and monitoring, including Safety/Water/Maintenance Management, Backfill monitoring/Mining control, and more. 2) Executing, including operating surface tele-remote rock breakers and LHDs. 3) Reporting and analytics.” Could you please elaborate on the current stage of the rollout?

Response provided by Key Interview Respondent 5 (KIR5)

I am not fully aware of Johan Slieps deployment plan, but to the above:

The deployment of the mine's technology execution strategy, as outlined by Johan Sliep, has progressed significantly since its initiation in 2019, with advancements across the three horizons:

1. Planning, Scheduling, and Monitoring

Current Status:

- Safety Systems: Deployment of Collision Avoidance Level 9 (CAS L9) is underway, aiming for full compliance with DMRE requirements after previous gaps were identified.

- Maintenance Management: Integrated platforms are being developed to monitor and predict equipment health, reducing unplanned downtime.

- Backfill Monitoring: Enhanced systems are providing real-time data on backfill operations, ensuring mine stability and process efficiency.

- Mining Control: Implementation of underground network upgrades enables better monitoring and control of mining activities, including improved communication between surface and underground operations.

2. Execution

Current Status:

- Tele-Remote Operations: Tele-remote capabilities for rock breakers and Load-Haul-Dump (LHD) machines are operational in key areas, with plans to expand. This has improved productivity by allowing operations in hazardous or inaccessible zones.

- Automation of Key Processes: The mine is adopting robotic process automation (RPA) to streamline repetitive administrative and operational tasks, enhancing overall efficiency.

- Network Infrastructure: Continued investment in underground digital infrastructure supports the expansion of tele-remote operations and other automation initiatives.

3. Reporting and Analytics

Current Status:

- Integrated Reporting Platforms: Development of centralized data systems is enabling real-time analytics and reporting. These systems improve decision-making by offering insights into performance metrics across safety, productivity, and equipment health.

- Data Utilization: A Nerve Centre is being established to aggregate and analyze data from multiple systems, fostering proactive decision-making and operational transparency.

- AI and Machine Learning: Initial steps in leveraging AI-driven analytics for predictive insights and process optimization have been taken, with plans for broader integration.

? Out of the six mining cycle pillars, our focus is on operations (productivity), specifically on mineral/ore and waste extraction. This area branches into drill-and-blast and mechanized, autonomous mining. Each of these value drivers encompasses technologies with the potential to add value. Can you provide a summary of the technologies deployed under these categories? For example, under mineral ore and waste extraction, drill-and-blast might include blast design and drill pattern as value drivers, utilising technologies such as unmanned aerial vehicles (UAVs) and Augmented Reality. Please elaborate on the specific technologies deployed in this context.

Response provided by Key Interview Respondent 7 (KIR7)

Blast Design and Drill Pattern Optimization Software

Integrated Planning and Scheduling project

? Can you assign the technology types to the following categories: those that are for business survival (operating cost optimization) and those that are for profitability (growth strategies), safety, etc.

Response provided by Key Interview Respondent 6 (KIR 6)

Currently we are only focusing on safety and productivity improvement initiatives.

3. Workforce Structure

? Can you describe the current structure of the workforce at the mine in terms of age, education, experience, and current job roles?

- Will get this data – Data was never released

? How has the mine's workforce evolved over the past five years?

Response provided by Key Interview Respondent 2 (KIR 2)

- Focus on recruitment policies and workforce planning, procedures and processes has led to better selection of new employees, however there is a lot more work needed in this space

? Following the 80/20 Pareto principle, what roles and positions were essential for the mine's operations prior to modernisation?

Response provided by Key Interview Respondent 1 (KIR 1)

Production Roles

- Miners and Machine Operators: Directly responsible for drilling, blasting, and ore extraction.
- Shift Supervisors: Coordinated underground operations, ensuring safety and productivity.
- Artisans and Technicians: Maintained mining equipment and infrastructure, such as hoists, conveyors, and drilling machinery.

Safety and Compliance

- Health and Safety Officers: Ensured compliance with regulations and minimized workplace hazards.
- Environmental Officers: Managed environmental impact and rehabilitation initiatives.

Technical and Support Staff

- Geologists and Surveyors: Identified ore bodies and provided precise mapping of underground areas.
- Engineers: Focused on mine planning, ventilation, and overall operational efficiency.

Administrative and Logistical Support

- Logistics Coordinators: Managed material transport, inventory, and supply chains.
- HR and Payroll Officers: Ensured smooth workforce operations and maintained employee welfare.

? What roles and positions will be essential for the modernised mine?

Response provided by Key Interview Respondent 5 (KIR5)

Technology and Automation Specialists

- Automation Engineers: Design, maintain, and optimize automated systems like autonomous vehicles, robotic drills, and conveyor systems.
- Artificial Intelligence (AI) Specialists: Develop and manage AI models for predictive maintenance, operational efficiency, and safety enhancements.
- Data Analysts: Analyse big data from sensors and IoT devices to improve decision-making and productivity.

Digital Transformation and Systems Experts

- Digital Transformation Leads: Oversee the integration of digital solutions, ensuring alignment with strategic goals.
- IT and Cybersecurity Specialists: Protect critical digital infrastructure and systems from cyber threats.
- IoT Technicians: Manage interconnected devices and systems, ensuring seamless data exchange and functionality.

Human-Machine Collaboration Facilitators

- Human Factors Specialists: Focus on optimizing interactions between workers and machines, improving safety and efficiency.
- Change Management Consultants: Guide workforce adaptation to new technologies and processes.

Sustainability and Ethical Oversight

- Sustainability Officers: Implement strategies to minimize environmental impact and improve energy efficiency through green technologies.
- Ethics and Compliance Managers: Ensure the ethical use of AI and adherence to legal standards in mining operations.

Upskilled Operational Roles

- Smart Equipment Operators: Operate and monitor advanced machinery via digital interfaces or remote systems.
- Technicians for Advanced Systems: Maintain and repair sophisticated equipment, blending mechanical and IT expertise.

Leadership and Strategic Roles

- Innovation Strategists: Drive continuous improvement by identifying emerging technologies and integrating them into operations.
- Workforce Development Specialists: Design and implement training programs to reskill and upskill employees for new roles.

- **Identifying and Addressing Skill Gaps:**

? Are there any plans or processes already in place for conducting skill assessments or competency evaluations of the existing workforce to define readiness for modernisation and identify skill gaps?

Response provided by Key Interview Respondent 1 (KIR1)

- As the organisation evolves, new skill is determined by the change in ways of work or the use of different mining methods. Skills are matched to the need of the organisation and new skill recruited into the organisation go through a pre-assessment process in order for the employee meet the business requirement. Constant evaluation is done of hard-to-fill vacancies which then form part of a scarce skill analysis, and as a result plans then initiated to address these skill gaps.

? What key skills, competencies, and qualifications do you think the current workforce will need to adapt to leverage Human Cyber Physical Systems (HCPS) effectively and support the mine modernisation process at large?

Response provided by Key Interview Respondent 3 (KIR3)

- There is a definite need to for employees to understand data analysis and how this will assist in better planning. As the organisation modernises, more data is extracted from processes, however is not used as it should be.

? What resources or training programmes will be made available to employees to acquire the mentioned competencies (e.g., training modules: content, duration, and effectiveness)?

Response provided by Key Interview Respondent 4 (KIR4)

- The introduction of more digitally designed training content, and blended learning programmes that supports modernisation. Immersive training is an example of creating a better learning experience and have engaged employees.

? Are there any plans for cross-functional training or job rotations to enhance versatility?

Response provided by Key Interview Respondent 3 (KIR3)

- Yes, this will be a nee d in the future organisation, however it will be restricted with the discipline, due to legislative and specific competencies.

?Operating under the typical difficult South African narrow-reef conditions, which may sometimes limit access to mechanization, did this make training the workforce significantly more difficult?

- This transition is dependent on a critical change management process. Some employees are usually re-skilled to move into the new environment. This is also conditional to requirements of the new job. One major issue is the levels of literacy of employees in comparison of conventional mining vs mechanised.

?What is the potential to retain staff that could not be upskilled?

- Again, this is meeting the requirement of the new job.

- Are there plans to hire new talent externally to fill the identified required talent?
    - Some % of skill will always be externally recruited due to the nature of work and job requirement. This also dependent on the training offering and whether or we can skill or source a provider to develop the skill

4. Planning and Reorganising the Workforce:

? Could you please provide insights into the company's long-term strategic approach to planning the workforce structure and determining the number and qualifications of the workforce?

Response provided by Key Interview Respondent 1 (KIR1)

Alignment with Strategic Goals

- Our workforce planning is closely aligned with the company's goals for increased automation, sustainability, and profitability.
- Anticipating future technological, regulatory, and market trends to shape the workforce structure.

Skills and Qualifications Mapping

- Conducting skills audits to identify gaps in existing competencies.
- Mapping skills required for roles like automation specialists, data scientists, and sustainability officers.
- Emphasising the need for employees with cross-functional expertise (e.g., combining mining knowledge with IT or AI skills).

Workforce Structure and Numbers

- Incorporating a mix of full-time, contract, and remote workers to adapt to dynamic operational needs.
- Preparing the next generation of leaders by identifying and nurturing talent.

? Could you please elaborate on how the company plans to execute short-term workforce management with regards to planning and scheduling within the current permanent staff where there is a need to reassign tasks?

Response provided by Key respondent 2 (KIR2)

Dynamic Task Reassignment

- Identify critical tasks that require immediate reassignment due to automation or operational changes.
- Match employees' skills with the requirements of emerging roles. For instance, a technician previously focused on mechanical maintenance may transition to operating or monitoring automated equipment.
- Implement cross-functional teams to cover critical areas when needed.

Real-Time Scheduling Systems

- Use workforce management software to create real-time schedules and reassign tasks quickly.
- Adjust shift patterns to ensure adequate coverage for high-priority operations, especially during transitional periods.
- Regularly monitor task completion and employee feedback to refine scheduling.

Training for Reassigned Roles

- Providing immediate training for employees transitioning into new roles, such as operating modernized equipment.
- Pair employees with experienced personnel or external specialists to build confidence and skills in unfamiliar tasks.

Communication and Transparency

- Inform our employees about the reasons for reassignments, the expected outcomes, and the benefits of the changes.
- Involve our employees in planning their task transitions to foster a sense of ownership and reduce resistance to change.

? How does short-term employee retask planning focus on assigning individuals to tasks based on existing abilities, potentially following priority rules that consider logistical, financial, and ergonomic goals to establish the talent pool?

Response provided by Key Interview Respondent 2 (KIR2)

Talent Pool Assessment

- Maintain an up-to-date database of our employees' skills, certifications, and experiences.
- Leverage historical performance records to identify employees who excel in specific tasks.
- Define the skills, knowledge, and physical requirements for each task to match them to suitable employees.

Logistical Goals:

- Assign employees based on proximity to the task location to reduce travel time and improve efficiency.
- Optimize team compositions to ensure critical operations are covered without disrupting workflows.

Financial Goals:

- Prioritise employees already on-site to minimize overtime or additional hiring costs.
- Use available talent to prevent expensive downtime for machinery or systems.

Ergonomic Goals:

- Avoid assigning physically demanding tasks to employees prone to injury or fatigue.
- Rotate tasks to balance workload and reduce strain on specific individuals.

Task Matching Process

- Use workforce management software with algorithms to suggest task assignments based on predefined criteria (skills, availability, and location).
- Supervisors review and approve assignments to ensure alignment with broader operational goals.

Establishing the Talent Pool

- Encourage employees to acquire secondary skills, expanding the available talent pool for diverse tasks.
- Identify and maintain a group of versatile employees capable of stepping into high-priority roles when needed.
- Categorise employees into tiers based on their proficiency and readiness for task reassignment.

5. **Impact Assessment of Technologies:**

? How do you assess the potential of these technologies to upskill the current workforce?

Response provided by Key Interview Respondent 6 (KIR6)

- Upskill our operators to use semi-autonomous drills by teaching them to programme machines and analyse performance data.
- Train our maintenance staff to use IoT devices for predictive maintenance, reducing breakdowns and improving efficiency.
- Offering courses in data visualisation and interpretation for employees working with AI-powered dashboards to optimise operations.

? What strategies are in place to retain staff, particularly those who may find it challenging to adapt to new technological requirements?

Response provided by Key Interview Respondent 1 (KIR1)

Training and Support Programmes

- Offering training to ensure employees are not overwhelmed by complex technological changes.
- Training programmes based on individual learning needs, starting with foundational digital literacy and progressing to advanced skills.
- Pair less tech-savvy employees with tech-proficient colleagues or mentors to provide hands-on support and encouragement.

Role Reassignment and Redeployment

- Identify roles within the company that rely less on advanced technology but are equally valuable.

- Adjust job descriptions to incorporate a balance of technological and traditional tasks, allowing employees to contribute meaningfully while building their digital competencies.
- Temporarily assign employees to roles where they can observe and gradually learn about technological applications without immediate performance pressures.

? Are there opportunities for onboarding workers who may have been previously limited by physical or other attributes due to the implementation of new technologies?

Response provided by Key Interview Respondent 6 (KIR6)

- The implementation of advanced technologies, such as automation, remote operation systems, and robotics, creates unique opportunities for workers who may have been excluded due to physical limitation.

? What new skills and competencies will the workforce require, and do these skills necessitate longer training periods or a higher level of aptitude?

Response provided by Key Interview Respondent 4 (KIR4)

Digital Literacy
- Basic proficiency with computers, mobile devices, and software applications.

Data Analytics and Interpretation
- Ability to analyse data generated by IoT devices, sensors, and AI systems to optimize operations.

Automation and Robotics Operation
- Skills to operate, maintain, and troubleshoot automated machinery and robotic systems.

Cybersecurity Awareness
- Understanding of basic security protocols to protect systems from breaches.

Critical Thinking and Problem-Solving
- Ability to make quick decisions based on system feedback and resolve operational challenges.

Systemic Thinking
- Understanding interdependencies between processes and technologies for optimized decision-making

Collaboration and Communication
- Effectively working in cross-disciplinary teams that include human and AI collaborators

Remote Operations Management
- Operating and overseeing equipment from remote control rooms.

While some roles demand longer training and higher aptitude, effective planning ensures all employees are equipped to thrive.

? How do the qualifications of workers influence the likelihood of human error in operations, and what measures are being taken to minimize this risk?

Response provided by Key Interview Respondent 7 (KIR7)

- Our employees' qualifications play a significant role in reducing human error in our operations. A well-trained and qualified workforce is more likely to make informed, accurate decisions, operate complex systems effectively, and follow safety protocols, thereby minimizing operational risks. However, even the most qualified workers are susceptible to errors under certain conditions, such as stress, fatigue, or inadequate support.
- By providing continuous training programmes ensure that our workers are not only familiar with new technologies but also retain a high level of expertise in older systems. Training also emphasizes situational decision-making, reducing the impact of human error in high-stakes situations.
- Clear and regularly updated SOPs provide our workers with structured guidelines for tasks, reducing ambiguity and the risk of error. This ensures consistency in how operations are conducted, regardless of technological advancements
- Regularly reviewing errors, accidents, or near-misses helps identify root causes and prevent recurrence. Encouraging a culture of continuous improvement and learning helps the workforce understand where they can enhance their skills or processes.

? Can you elaborate on how these technologies are expected to improve safety, specifically in terms of reducing the likelihood and severity of potential harm?

Response provided by Key Interview Respondent 6 (KIR6).

- Autonomous systems, such as automated drilling, and robotic loaders, remove humans from the most dangerous tasks. These systems can work in high-risk environments (e.g., underground and extreme conditions) without risking human lives.
- Sensors and IoT devices installed in mining equipment and infrastructure allow for continuous monitoring of conditions such as equipment health, air quality, and structural integrity. Predictive analytics forecast potential issues, enabling timely maintenance and repairs before they result in catastrophic failures.
- Wearable devices, such as our lamps with Collison Avoidance System (CAS), track worker. CAS can send alerts if a worker is in distress, enabling immediate assistance.

? In what ways do these technologies help reduce the risk of human error, thereby decreasing the likelihood of operational blunders or mishaps?

Response provided by Key Interview Respondent 6 (KIR6).

- Technologies are playing a critical role in reducing human error by automating tasks, providing real-time feedback, and supporting decision-making. By minimizing the opportunities for human error, these technologies not only improve operational efficiency but also significantly reduce the risk of accidents.

6. **Change Management:**

? How will potential resistance to change be addressed?

Response provided by Key Interview Respondent 1 (KIR 1).

Comprehensive Change Management Strategy

- Clear Vision and Communication
- Regularly communicate the goals, benefits, and progress of modernization efforts to all employees.
- Use multiple platforms (town halls, newsletters, and interactive sessions) to ensure transparency and build trust.

Stakeholder Engagement

- Involve key stakeholders, including unions, supervisors, and frontline workers, early in the process to gather feedback and build consensus.
- Establish change champions within teams to advocate for modernization initiatives and address concerns at a grassroots level.

Workforce Development and Skills Training

- Upskilling and Reskilling Programs
- Implement targeted training programs to prepare employees for new roles, ensuring they feel equipped and confident to adapt to technological changes.
- Use immersive tools like virtual reality (VR) for hands-on training in operating advanced machinery or tele-remote systems.

-Career Pathways

- Clearly outline new opportunities arising from modernization (e.g., roles in automation, data analytics, and control centers) to demonstrate the long-term benefits for employees.

Inclusive Technology Deployment

- Addressing Fears and Misconceptions
- Job Security Assurance
- Proactively address concerns about job displacement by emphasizing how automation will complement human roles, not replace them.
- Highlight initiatives that focus on redeployment rather than redundancy.

7. **Performance Evaluation and Incentives:**

? How will the mine measure the success of the modernisation efforts concerning the workforce?

Response provided by Key Interview Respondent 7 (KIR7).

- The mine under study tracks key metrics such as output per worker, task completion times, and downtime reductions from automation. Monitoring safety incident rates and employee safety perceptions is crucial, alongside assessing training completion, upskilling success, and competency. Additionally, calculating cost savings, ROI, revenue growth from modernization, and measuring employee adaptability, will provide a comprehensive view of the impact.

? Does the company have processes in place to show that by measuring skills, leadership can track the business impact of the learning and development budget?

Response provided by Key Interview Respondent 7 (KIR7).

- Regular evaluations (e.g., competency assessments or skills matrices) are conducted to measure improvements in employee skills, ensuring alignment with business goals.
- Linking learning outcomes to specific business performance indicators, such as productivity, quality, safety, or innovation, helps assess how development programmes are driving tangible business results.
- Tracking career advancement of employees who underwent training helps demonstrate how L&D investments support talent growth and reduce turnover.
- Comparing the costs of training programmes to the business benefits, such as increased output or reduced downtime, provides insights into ROI.
- Gathering feedback from employees about the relevance and impact of training ensures that programmes are meeting both personal and business needs.

8. Diversity and Inclusion

? How will the mine address diversity and inclusion during the re-organisation process?

Response provided by Key Interview Respondent 2 (KIR 2).

- "The company"Way programme ensure that our leadership at all levels are trained in diversity and inclusion principles, promoting a culture that values different backgrounds, perspectives, and experiences.
- We ensure that all our employees, regardless of gender, race, or background, have equal access to new roles, training, and career advancement opportunities.
- We maintain open and transparent communication with employees about the reorganization process, emphasizing the importance of diversity and inclusion in decision-making and change management.
- Continuously monitor diversity and inclusion metrics throughout the reorganization, gathering feedback from employees to ensure the process is fair and inclusive.

- Are there efforts to ensure equal opportunities for all employees in the modernized mine?
    -
- Is there a strategy for local community inclusion?
    -

9. **Collaboration with Educational Institutions**

? Are there any collaborations with educational institutions or vocational training centers to support the mine's workforce needs?

Response provided by Key Interview Respondent 4 (KIR 4).

- Yes, we partner with local high schools and technical colleges to source and develop local students.

? How will the mine engage with these institutions to develop talent pipelines?

Response provided by Key Interview Respondent 4 (KIR 4).

- We provide weekend math and science classes to local high school students after identifying these subjects as key areas of academic development that were hindering students' university acceptance to become our bursars. Additionally, these high schools refer students who meet the criteria to study at the local technical college, Westcol, for engineering studies. These two streams serve as our pipeline for training artisans and graduates. Our bursars who complete our graduate programme and can go on to become future engineers, geologists, metallurgists, HR professionals, and more.

10. **Future Outlook: - Response never received**

- Where do you see the mine's workforce in the next 10 to 20 years, after the modernisation process?
- How will the mine continue to adapt its workforce management strategy to keep up with evolving technologies and industry trends?

11. **Human-Centric Technology Adoption:**

? Would you say that the mine under study has prioritised human dimensions over the technology strategy and set clear technological transformation targets to experience a smoother transition to 5IR technologies?

Response provided by Key Interview Respondent 7 (KIR 7).

The mine under study has made notable strides in balancing the human dimensions and technology strategy to facilitate its transition to 5IR technologies. The mine's focus on upskilling, reskilling, immersive training, and change management demonstrates a clear prioritization of workforce readiness and acceptance alongside technological advancements. Efforts to address resistance, foster open communication, and ensure job security further underline its commitment to the human element. However, while these initiatives are robust, clearer and more measurable technological

transformation targets, combined with deeper employee involvement in technology co-creation, could enhance alignment and ensure an even smoother transition to 5IR innovations.

12. Emerging Technologies Perception:

? What is your perception of the potential impact of emerging 5IR technologies like Human-Cyber Physical Systems (HCPS) on the mining industry regarding the workforce?

Response provided by Key Interview Respondent 6 (KIR6).

Emerging 5IR technologies, such as Human-Cyber Physical Systems (HCPS), have the potential to profoundly transform the mining workforce by fostering a collaborative relationship between humans and intelligent systems. These technologies enhance safety and productivity by automating hazardous tasks, enabling real-time decision-making, and optimizing operations. For the workforce, this shift offers opportunities for upskilling and transitioning into more analytical, supervisory, or creative roles that leverage human intuition alongside machine intelligence. However, it also necessitates proactive change management to address fears of job displacement, ensure equitable access to training, and cultivate a culture that embraces innovation. Ultimately, HCPS could redefine the mining workforce as a tech-savvy, adaptive, and highly integrated component of modern mining operations.

Response provided by Key Interview Respondent 7 (KIR 7).

“We don’t particularly care to categorise our technology under any specific industrial revolution. As an engineer, I’m concerned with the utility and effectiveness of the equipment and the system.”

APPENDIX D
Glossary of Terms

i. Mine of the Future

A technologically advanced, highly automated, and sustainable mining operation that integrates Fourth and Fifth Industrial Revolution (4IR and 5IR) technologies to enhance efficiency, safety, and environmental responsibility. It leverages AI, robotics, automation, IoT, digital twins, and smart sensors to optimise operations, reduce human risk, and improve decision-making. Additionally, it emphasises a human-centric approach, ensuring workforce inclusion, skill adaptation, and long-term sustainability in mining.

ii. The Social and Labour Plan (SLP)

A regulatory requirement under the Mineral and Petroleum Resources Development Act (MPRDA) of 2002, aimed at promoting socio-economic development in South African mining communities. It is a key instrument for ensuring that mining companies contribute to local economic growth, skills development, job creation, and community upliftment, both during and after mining operations.

iii. Bluetooth

A short range wireless communication technology designed for connecting devices within a limited range, typically under 10 metres (33 feet). It is often used for personal area networks (PANs).

iv. Wi-Fi

A wireless communication technology that enables devices to connect to a local area network (LAN) and the internet over longer distances (typically up to 100 metres indoors). It is part of the IEEE 802.11 family of standards.

v. Development Drill

A machine used to drill holes for blasting during the development phase of an underground mine. Development drills create tunnels or drifts to access ore bodies. They are designed for fast and efficient drilling in confined spaces, with features such as boom-mounted drills and automation for precision.

vi. Bogger

A Load-Haul-Dump (LHD) machine used for mucking, which involves scooping up broken rock or ore and transporting it to ore passes or trucks. Boggers are compact and highly manoeuvrable to operate efficiently in narrow underground spaces.

vii. Charge Wagon

A specialised vehicle designed to transport and deliver explosives for charging blast holes. Charge wagons are equipped with compartments and mechanisms to ensure safe and precise placement of explosives in underground mining operations.

viii. Cable Bolter

A machine used for installing cable bolts in underground mines. Cable bolts are long, flexible steel cables grouted into drilled holes to provide rock reinforcement and improve ground stability in tunnels, stopes, and other mining areas.

ix. Production Drill

A drilling machine used to create blastholes during the production phase of mining. These holes are filled with explosives to break the ore into manageable pieces for extraction. Production drills are designed for high-speed drilling and accuracy in large-scale mining operations.

x. Haul Truck

A heavy duty truck used to transport broken ore or waste rock from the mine to a designated dumping area, such as ore passes, crushers, or surface stockpiles. Underground haul trucks are specifically designed for narrow tunnels and steep inclines, with robust construction and high payload capacities.

APPENDIX E – Input tables used for workforce trends calculations

BAND	NQF	OLD SYSTEM	Male				Female				Total		Total
			African	Coloured	Indian	White	African	Coloured	Indian	White	Male	Female	
General Education and Training (GET)	1	No Schooling / Unknown	60	0	0	22	40	1	1	5	82	47	129
		Grade 0 / Pre	0	0	0	0	0	0	0	0	0	0	0
		Grade 1 / Sub A	18	0	0	0	0	0	0	0	18	0	18
		Grade 2 / Sub B	5	0	0	0	0	0	0	0	5	0	5
		Grade 3 / Std 1 / ABET 1	92	0	0	0	1	0	0	0	92	1	93
		Grade 4 / Std 2	66	0	0	0	3	0	0	0	66	3	69
		Grade 5 / Std 3 / ABET 2	83	0	0	1	5	0	0	0	84	5	89
		Grade 6 / Std 4	91	0	0	0	3	0	0	0	91	3	94
		Grade 7 / Std 5 / ABET 3	160	0	0	0	9	1	0	0	160	10	170
		Grade 8 / Std 6	153	0	0	0	7	0	0	0	153	7	160
		Grade 9 / Std 7 / ABET 4	180	0	0	2	12	0	0	0	182	12	194
Further Education and Training (FET)	2	Grade 10 / Std 8 / N1	205	0	0	28	48	3	0	2	233	53	286
	3	Grade 11 / Std 9 / N2	320	1	1	28	117	0	0	0	350	117	467
	4	Grade 12 / Std 10 / N3	720	8	5	125	345	5	4	30	858	384	1,242
Higher Education and Training (HET)	5	Diplomas / Certificates	220	0	2	98	109	3	1	12	320	125	445
	6	First degrees / higher diplomas	51	4	1	8	35	2	0	4	64	41	105
	7	Honours / Master's degrees	23	2	1	2	16	0	1	1	28	18	46
	8	Doctorates	1	1	0	0	1	0	0	0	2	1	2
TOTAL			2448	16	10	314	751	15	7	54	2,788	827	3,615

Table 14: Leadership Plans for 2018 – 2022

YEAR		ENGINEERING		Junior Engineer	MINING	
		18.1	18.2		18.1	18.2
2018	Cont.	48	80	23	52	18
	New Intake	0	0	0	0	0
2019	Cont.	28	52	11	24	9
	New Intake	0	0	0	0	0
2020	Cont.	7	26	7	2	3
	New Intake	0	0	0	2	0
2021	Cont.	0	0	6	2	1
	New Intake	4	3	0	2	2
2022	Cont.	4	3	6	4	3
	New Intake	4	3	0	4	3
TOTALS	**Cont.**	**87**	**161**	**53**	**84**	**34**
	New Intake	**8**	**6**	**0**	**8**	**5**

Table 14: Leadership Plans for 2018 – 2022

YEAR		ENGINEERING		Junior Engineer	MINING	
		18.1	18.2		18.1	18.2
2018	Cont.	48	80	23	52	18
	New Intake	0	0	0	0	0
2019	Cont.	28	52	11	24	9
	New Intake	0	0	0	0	0
2020	Cont.	7	26	7	2	3
	New Intake	0	0	0	2	0
2021	Cont.	0	0	6	2	1
	New Intake	4	3	0	2	2
2022	Cont.	4	3	6	4	3
	New Intake	4	3	0	4	3
TOTALS	**Cont.**	**87**	**161**	**53**	**84**	**34**
	New Intake	**8**	**6**	**0**	**8**	**5**

Table 37: Demographic Profile in Decision-Making Positions as at June 2018

Occupational Level	Female				Male				Total	Disabled	
	A	C	I	W	A	C	I	W		Male	Female
Top Management (Board)							1	2	3		
Senior Management (Exco)	1	0	0	1	1	0	0	4	7	0	0
Middle Management	19	4	2	7	55	9	8	76	180	1	0
Junior Management	25	2	0	16	168	3	5	83	302	2	0

Occupational Level	Female				Male				Total	Foreign Nationals
	A	C	I	W	A	C	I	W		
Core Skills	274	10	4	39	976	11	6	274	1 821	227

Development Progression levels	Mechanized Mining Career Path (Excluding Logistics)	Grade	Dover Test	Preferred Requirements	Mandatory requirements	Drivers License	Computer Literacy	Basic Rock Mechanic's	Hydraulics Appreciation Course	Machine Specific Training	Mechanized Mining Experience
12	Senior Operations Manager	EU	Yes	Mining Degree / Diploma / GIBBS - MDP / LDP / POLC course	Mine Managers Certificate, Professionals Registrations, Safe Production Rules, Health and Safety course	Yes	Yes	No	No	No	15 Years
11	Operation Manager	EL	Yes	Mining Degree / Diploma / GIBBS - MDP / LDP / POLC course	Mine Managers Certificate, Professionals Registrations, Safe Production Rules, Health and Safety course	Yes	Yes	No	No	No	12 Years
10	Unit Manager	DU	Yes	Mining Degree / Diploma / GIBBS - MDP / LDP	Mine Managers Certificate, Professionals Registrations, Safe Production Rules, Health and Safety course	Yes	Yes	No	No	Progressed through levels	10 Years
9	Mine Overseer	DL	Yes	Mine Managers Certificate / Grade 12 / GIBBS - MDP / LDP	Mine Overseer Certificate, Safe Production Rules, Health and Safety course	Yes	Yes	Yes	Yes	Progressed through levels	8 Years
8	Production Supervisor	CU	Yes	M O Certificate / Grade 12, Assessors Certificate / POLC course	Blasting and Production Supervisors Certificate, Methane Test Certificate, Safe Production Rules, Health and Safety course	Yes	Yes	Yes	Yes	Progressed through levels	6 Years

Development Progression levels	Mechanized Mining Career Path (Excluding Logistics)	Grade	Dover Test	Preferred Requirements	Mandatory requirements	Drivers License	Computer Literacy	Basic Rock Mechanic's	Hydraulics Appreciation Course	Machine Specific Training	Mechanized Mining Experience
7	Crew leader	CU	Yes	Leaner Official Prog / Grade 12 / POLC course	Blasting Certificate, Certificate, Safe Production Rules, Health and Safety course	Yes	Yes	Yes	Yes	Progressed through levels	4 Years
6	Drill rig Operator / Support rig Operator / Long hole Rig Operator	CL	Yes	Blasting Certificate, Grade 10	Comp A, Safe Production Rules, Health and Safety course	Yes	No	Yes	Yes	10 Days	30 Months
5	LHD Operator	CL	Yes	Blasting Certificate, Grade 10	Comp A, Safe Production Rules, Health and Safety course	Yes	No	Yes	Yes	10 Days	24 Months
4	Dumptruck Operator / Grader Operator / Dozer Operator	BU	Yes	ABET 4	Comp B, Safe Production Rules, Health and Safety course	Yes	No	No	Yes	10 Days	18 Months
3	Scaler Operator/ Utility Vehicle Operator/ Charmec Operator/Spraymec Operator	BU	Yes	ABET 3	Comp B, Safe Production Rules, Health and Safety course	Yes	No	No	Yes	5 Days	12 Months
2	Impact Breaker Operator	BL	Yes	ABET 2	Comp B, Safe Production Rules, Health and Safety course	No	No	No	Yes	3 Days	6 Months
1	General Labourer	AU	No	ABET 1	Comp B, Safe Production Rules, Health and Safety course	No	No	No	No	Nil	None
*Duration of Training and Development dependent on individual performance, competence and progression *Valid First Aid Certificate and Medical Certificate of Fitness are compulsory for all underground employees											

Occupation Level	Job title of Vacancy	Hard To Fill	Vacant	Main Reason for being unable to fill the vacancy
Top Management	N/A			N/A
Senior Management	Mine Manager			Relative scarce skill – employment equity
Professionally qualified and experienced specialists and mid-management	Engineer		X	Relative scarce skill – employment equity
	Rock Engineer	X	X	Absolute – lack of skilled people in South Africa
	Resource Geologist		X	Absolute – lack of skilled people in South Africa
	Mine Planner		X	Absolute – lack of skilled people in South Africa
	Geologist	X	X	Absolute – lack of skilled people in South Africa
	Surveyor			Absolute – lack of skilled people in South Africa
Skilled technical and academically qualified workers, junior management, supervisors, foreman and superintendents	Instrument Mechanician	X	X	Absolute – lack of skilled people in South Africa
	Diesel Mechanic		X	Absolute – lack of skilled people in South Africa
	Electrician		X	Absolute – lack of skilled people in South Africa
	Boiler Maker		X	Absolute – lack of skilled people in South Africa
	Electrician (Engineering)		X	Absolute – lack of skilled people in South Africa
	Dump Truck Operator	X	X	Absolute – lack of skilled people in South Africa
	Drill Rig Operator		X	Absolute – lack of skilled people in South Africa
	Fitter and Turner		X	Absolute – lack of skilled people in South Africa
	Load-haul-dump (LHD) Operator		X	Absolute – lack of skilled people in South Africa
	Rigger			Absolute – lack of skilled people in South Africa
	Production / Operations Supervisor (Mining			Absolute – lack of skilled people in South Africa
	Miner		X	Absolute – lack of skilled people in South Africa
Semi-skilled and discretionary decision making	N/A			N/A
Unskilled and defined decision making	N/A			N/A

Table 6: Form R hard-to-fill vacancies aligned to Workplace Skills Plan & Annual Training Report

Occupation or Specialisation Title	Reason for Occupation being Scarce	Add comments regarding the scarcity, i.e. which tasks/outputs that are critical for the occupation are not being met or performed by employees.	What type of learning programmes are you planning to address this occupational scarcity?	NQF Level
Boiler Maker	Absolute – replacement demand	Machinery maintenance	MQA_ Learnership	3
Diesel Mechanic	Absolute – replacement demand	Machinery maintenance	MQA_ Learnership	4
Electrician (Engineering)	Absolute – replacement demand	Machinery maintenance	MQA_ Learnership	4
Dump Truck Operator	Absolute – replacement demand	Tramming	Short Course	2
Drill Rig Operator	Absolute – replacement demand	Drilling and Blasting	MQA_ Learnership	2
Fitter and Turner	Absolute – replacement demand	Maintenance	MQA_ Learnership	3
Load-haul-dump (LHD) Operator	Absolute – replacement demand	Tramming	Short Course	2
Rigger	Absolute – replacement demand	Infrastructure Maintenance	MQA_ Learnership	3
Production / Operations Supervisor (Mining)	Absolute – replacement demand	Production	Short Course	4
Miner	Absolute – replacement demand	Production	MQA_ Learnership	3