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EVALUATING THE IMPACT OF NEW TECHNOLOGIES ON HAZARD PREVENTION AND RISK MITIGATION AND THE CHALLENGES AFFECTING THEIR SUCCESSFUL IMPLEMENTATION TOWARDS IMPROVING MINE SAFETY AND CONTRACTOR WELL-BEING

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DECLARATION

I, Lucia Mudari, do hereby declare that this work is completely the product of my own research and it has never been used for any other academic work. All references to previously published work have been clearly through in-text citations and a properly formatted reference list.

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DEDICATION

This research is dedicated to the Mudari family for their warm support, encouragement, love and sacrifices throughout my entire journey.

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ABSTRACT

The mining industry is one of the most hazardous sectors globally, with persistent challenges in ensuring worker safety and wellbeing. This study went on to investigate the actual effectiveness of new technologies in hazard identification and risk mitigation and to also analyze the challenges associated with the implementation success of these new technologies. The research aimed to assess the effectiveness of various new technologies across different departments and also identify the practical challenges encountered during their implementation. The case study was done out at Selous Metallurgical Complex Zimplats in Chegutu district from February to May 2025.The research adopts a mixed-methods approach, combining quantitative data from structured questionnaires with close ended questions, historical accident trend analysis and qualitative insights from open ended interview questions. Safety performance indicators such as Lost Time Injuries (LTIs), emergency response times and number of fatigue related incidents were thoroughly analyzed before and after technology implementation. Descriptive and inferential Statistical analysis was used to make conclusions on the findings with the help of Statistical Package for Social Sciences (SPSS).

Twenty-five respondents (n=25) were purposively selected to participate in the study. The results owed statistically significant reductions in incidents, LTIs, response times and an increase in hazard detection rates. Cohen's d values indicated large effect sizes for most variables. Qualitative interview findings also supported this. However, a lot of challenges were also identified such as training gaps, financial constraints, resistance from employees and inadequate legislations.

The study concludes that new safety technologies play a transformative role in improving mine safety and contractor wellbeing, but their success is continuously hindered by strategic implementation, organizational support, financial constraints and regulatory alignment. The research offers practical recommendations and lays a foundation for future studies on adaptive safety systems in resource-intensive industries.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The mining industry is an important aspect of the global economy, acting as a primary source of raw materials for many sectors, such as construction, manufacturing, and energy. However, the mining sector also faces numerous safety and health challenges (Valluru et al., 2020). The mining industry employs 1% of the global labor force (ILO, 2021) but is responsible for 5% of occupational health and safety fatalities worldwide (Tsishla et al., 2021). Accidents and occupational-related fatalities are continuously recorded globally (Manu et al., 2020). According to the NSSA annual report (2021), 11% of work-related injuries in Zimbabwe are from the mining sector; therefore, the mining sector must adapt to these emerging technologies. The ILO (2021) states that approximately 2.3 million people die worldwide due to work-related illnesses and accidents (Tarique et al., 2020). To foster safety in all mining operations, it is imperative that inclusive safety procedures be integrated into feasibility studies for all the operations of the mine, whether in mineral exploitation, development, or rehabilitation (Dong et al., 2022).

In the past years, a range of traditional hazard prevention and risk mitigation strategies has evolved in multiple industries, including the mining industry. The strategies include methods such as regulatory compliance, physical-human inspections, personal protective equipment (PPE), geotechnical engineering controls, and standard operating procedures (Hustrulid et al., 2021). These methods have reportedly faced challenges due to the complexity of mining operations. A study carried out by Hustrulid et al. (2021) highlights the stagnation caused by inaccuracy and the lack of real-time monitoring due to reliance on these traditional strategies. Traditional hazard management approaches are becoming increasingly insufficient in addressing the complex and hazardous nature of mining operations; therefore, they fail to provide real-time, predictive, or proactive solutions, leaving workers, especially contractors, susceptible to risks (Bonsu et al., 2021). According to the ILO (2020), the mining industry still accounts for 8% of fatal accidents in spite of the significant progress that has been made through these occupational health and safety preventive controls. The mining sector is one of the industries with the most difficult challenges, and the use of digital technology such as the Internet of Things (IoT), cloud sensor analytics, big data, mobile technology, and artificial intelligence (AI) can help overcome these challenges in operations such as fleet management, mine mechanization, safety, health, exploration, environmental impact, and remote operations (Lööw, 2020). Dong, L. Deng et al. (2020) research shows that the dam failures of mine tailings storage facilities (TSFs), which have been recorded in previous years, such as the incident at Jagersfontein, South Africa, among many other tailings dam failure incidents, have harmed the credibility of several mines due to loss of life and environmental damage. Scenarios like these act as a push encouraging mining industries to monitor the structural health and safety management of the TSFs with the best, most efficient, and available technologies for the sustainability of the mining business. Therefore, emerging technologies have risen as alternatives to foster safety and abate the risk of mine TSF failure (Cacciuttolo, C. et al., 2024).

Emerging technologies have significantly transformed many industries, and the mining industry is no exception, as it has also witnessed this transformation in various processes, from the exploration stage to the final processing of the ore (Bhattacharyya, S.S., and Shah, Y., 2022). Over the years, the mining industry has shown increased interest in the use of drones, automation, and other emerging technologies to improve its safety and health outcomes in various applications, which include 3D mapping of the mining environment, ore control, rock discontinuities mapping, post-blast rock fragmentation measurements, and tailings stability monitoring, to name a few (J. Shahmoradi et al., 2020). Sustainable mining is also another aspect that digital technology (DT) has made a significant impact on, as it can provide information that is pivotal in decision-making or predictive maintenance. With the advancements in technology for drones used in safety monitoring, decisions about mine safety are now based on the utilization of geotechnical and environmental data to avert dangers (Lööw, 2022). The ongoing use of digital technology in the mining sector has shown improvements in the industry through the following ways: improved mapping of exploration and estimation of ore reserves, enhancement of techniques from material exploitation and marketing to sales and transportation, significant improvements in the dissemination of information, and enhanced safety operations, among other things (Horbery et al., 2019).

The development of automation in the mining sector has allowed numerous mining companies to remove a large number of employees from highly dangerous or harmful working conditions (Molaei et al., 2020). It has made it possible for employees to have fewer interactions with the minerals directly because of the use of automated mining rigs and trucks. Due to improvements in safety standards and productivity rates brought about by autonomous production systems, various mining companies are now investing more in automation (Castro, R. et al., 2015). Tubis et al. (2020) suggested that the use of automated technologies will offer some solutions to the growing challenges encountered by the mining sector.

However, despite these potential benefits, the adoption of these technologies has not been fully implemented, especially in developing contexts where infrastructure, funding, and technical resources are scarce (Nkosi et al., 2021; Simatele & Mabuza, 2024).Without an in-depth understanding of both the benefits and the challenges that come with the adoption of these new technologies, mining companies may struggle to implement effective, scalable, and sustainable safety interventions. Although mining companies aim for a zero target in mining operations, the inconsistent adoption of technology across different operational layers underscores these safety objectives (Buthelezi, M, .2024). There is therefore need to address these structural and operational barriers especially in contractor environments so that technological advancements benefit the whole workforce (MiningDoc, .2025). Therefore, there is need to thoroughly research on the challenges that limit technology adoption in contractor-managed sections and explore strategies to bridge these gaps, thereby enhancing hazard prevention and safeguarding contractor well-being.

1.2 PROBLEM STATEMENT

According to the International Labor Organization (ILO, 2023), mining accounts for less than 1% of the global workforce but contributes to over 8% of fatal workplace accidents annually. In response to the limitations posed by traditional hazard prevention and risk mitigation techniques, the mining sector has begun integrating new technologies such as Internet of Things (IoT) devices, artificial intelligence (AI), automated equipment, drone surveillance, and wearable biometric sensors to better its safety and health outcomes (Chaulya & Prasad, 2022; Zhang et al., 2023).There is a significant shortage of studies that assess the actual effectiveness of these technologies especially on the side of contractor well-being in mining operations. Additionally, the challenges associated with their widespread adoption stretching from organizational resistance and high capital costs to insufficient training and cybersecurity concerns are not well articulated in the literature. The purpose of this study is, therefore, to seek to bridge the gap by assessing the effectiveness of new technologies in hazard detection and risk mitigation while also identifying the key challenges that hinder their adoption. The research aims to provide actionable insights for improving mine safety and enhancing contractor well-being, especially in underrepresented mining regions where technological integration is still in its developing stages.

1.3 RESEARCH SIGNIFICANCE

The beneficiaries of this research include the host mining organizations, customers, and contracting workers. This research aims to shed light on how Zimplats, which is the study area, makes use of emerging technologies to reduce and avert challenges faced by its contracting workers, who make up a larger population of its workforce. The findings of this research can help regulatory bodies create more effective safety standards that are evidence-based. The insights will allow regulatory bodies like NSSA to develop guidelines and policies that leverage these new technologies, making them mandatory for all industrial operations. Highlighting the use of these technologies at Zimbabwe Platinum Mines will encourage wider adoption of safety-enhancing technologies in other industries. Further studies and research into the use of these technologies will hopefully lead to increased investment in the field of innovation and mining technology, resulting in more advancements that can be applied in other sectors in the coming years. When mining companies adopt these technologies, contract workers will benefit from reduced exposure to hazardous conditions. Not only will this reduce exposure to harmful working conditions, but as time goes on, contract workers will have more opportunities to develop their technological skills, thereby increasing their chances of employability in more developed regions. Hopefully, the findings of this research will serve as an eye-opener for external investors and stakeholders to invest more in mine safety technologies, as this will provide evidence that the outcomes will lead to a better reputation for the mines and potentially higher returns. The findings of this research also aim to assist mining firm managers to anticipate the challenges that come with adoption of these technologies. This understanding will allow them to implement proper technology adoption plans and intervene proactively.

1.3.1 RESEARCH OBJECTIVES

- To assess the effectiveness of new technologies in hazard detection and risk mitigation.

- To assess the challenges associated with the adoption of new technologies in the mining sector.

1.3.2 RESEARCH QUESTIONS

1. How effective are new technologies in detecting and mitigating hazards in the mining sector?

2. To what extent have new technologies improved contractor well-being and safety outcomes in mining operations?

3. What are the challenges being faced by mining entities in adopting these new technologies?

4. How do perceptions of risk, change resistance and workforce readiness affect the successful implementation of new technologies in mine safety?

1.3.3 RESEARCH ASSUMPTIONS

The interviewed population are to give meaningful and honest reviews of their knowledge on the research topic.

Research questions shall be in a manner which is easily converged by the target population

1.4 LIMITATIONS

Financial Limitations: Costs to travel to and from the study area.

The submission and collection of questionnaires is a barrier due to the distance and travel costs incurred. To address this, the researcher shall make use of online platforms, including WhatsApp and email, when the need arises.

Communication and literacy barriers: Part of the target population failed to understand and comprehend fluent English. When necessary, the researcher might be forced to use the local mother tongue for easier understanding.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter encompasses and focuses on the literature review, which consists of assessing the effectiveness and challenges associated with the use of new technologies in hazard detection and risk mitigation in mines.

2.1.2 DEFINITION OF KEY TERMS

- Emerging technologies—these are scientific and inventive advancements designed to enhance safety and health in industrial operations (Hu, J. & McKenzie, A., 2022). Examples in the context of mining include autonomous mining equipment, sensors, and real-time monitoring systems (International Council on Mining and Metals, 2023).

- Automation—this is the use of emerging technologies such as artificial intelligence (AI), machine learning (ML), robotics, and other advanced autonomous control systems for industrial or mining processes to reduce human intermediation in hazardous operations (Molaei et al., 2020).

- Unmanned Aerial Vehicles—these are commonly referred to as drones. They are aircraft systems that are remotely controlled either by a human operator or through autonomous means, but without a human operator on board (Smith et al., 2024).

- Safety Challenges - The mining industry faces many safety and health challenges due to its heavy and harmful operations (Valluru et al., 2020).

- Contractors - These are temporary contract workers often appointed in mining operations and other industrial operations. The mining industry usually employs contract workers in most of its operations (Valluru et al., 2020).

- Valluru et al. (2019), Stewart et al. (2019), and Valluru et al. (2020) are some of the literature reviews discussing the tendencies, practices, and encounters of contractors at host mining organizations.

2.2 THEORETICAL FRAMEWORK

2.2.1 SOCIO-TECHNICAL SYSTEMS THEORY

Technological advancements are having a vast influence on organizations; therefore, organizations require a flexible, custom-built change model to fit the social network of the particular organization. Socio-Technical Systems Theory, which was presented in a study carried out by Eric Trist and the Tavistock Institute at a coal mine in the U.K., recognizes that all systems are made up of the social system and the technical system (E. Zaeri et al., 2024). Socio-Technical Systems Theory emphasizes the interdependency between humans and machinery and also shapes both the technical and social conditions of industrial operations in a way that increases competence and keeps humanity safe (E. Zaeri et al., 2024). The socio-technical model of information systems was used as a framework to guide the analysis of twenty-five thorough interviews with globally disseminated digital technology experts working collaboratively at an industry-leading hi-tech mining solutions company. The results of the analysis exhibited a harmonious perception of the interdependency of human, environmental, and technological interfaces (W. Gabryk, 2024). The fundamental principles of socio-technical systems are mainly based on the combination of human elements and technical systems to enable new possibilities for work and, therefore, develop more ways for technological change. Trist et al. (2016) outlined the principles of STS as follows:

1. Joint optimization of the social system (people, culture, and organizational structure) with the technical system (tools, processes, and technological components such as autonomy).

2. Human-centered design: STS encourages that technologies should be designed in a way suitable for users, ensuring a “goodness of fit” between the social and technical factors of an organization.

STS was established as an open systems foundation, a theory that promises a new paradigm (Trist et al.) which encourages collaboration (men as complementary to the machine), innovation, and internal controls (self-regulating sub-systems) and also minimal levels of risks (R. Abbias & K. Michael 2023).

Socio-technical design is defined by Eric Mumford as a system that facilitates organisational innovation by recommending the removal of minority groups and substituting flatter hierarchies, multi-skilling, and group decision-making. Technology boosts human liberty, democracy, and inventiveness. Socio-Technical Systems Theory has developed a shift from heavy industry to a steady broadening of inquiry into advanced manufacturing technologies and the design of large-scale IT projects (Davis et al., 2019). Further studies and applications of the STS theory have reviewed socio-technical frameworks to account for technological development (Bednar & Welch, 2020). Robertson et al. (2019) provide a good example where STS has been applied in the biomedical engineering field, a socio-technical approach ethically aligned with an existing engineering design process.

STS is also functioning in the context of mining, where digitalization is at the core of the technological shift (Lund et al., 2024). Research has shown that the technological subsystem is more optimized than the social subsystem in the mining industry (Lund et al., 2024). Industry 4.0 represents the fourth industrial revolution through the integration of cyber and physical worlds via technology (M. Sony, 2024). Recent studies have demonstrated the implementation of unmanned aerial vehicles (UAVs), commonly known as drone technology, in the mining sector, which aligns with contemporary socio-economic technical systems. This adoption is supported by socio-technical theory.

2.2.2 RISK MANAGEMENT THEORY

A survey on modern challenges and pressures affecting companies, industries, and mines showed that occupational injuries remain an issue of concern despite all the measures being taken (M. Rudakov et al., 2021). The unending introduction of automation, information technology, and artificial intelligence in the mining sector has brought about numerous control rules. Digital technologies, state-of-the-art technologies, and intellectual systems, along with behavior-based safety programs, are all aimed at accident prevention (M. Rudakov et al., 2024). Complex and sometimes fatal accidents in the mining sector have compelled researchers to seek solutions to these emerging problems in different ways; therefore, they introduce a systematic approach and risk-based thinking to avert these problems. The risk-based approach is mostly instrumental in addressing the OSH challenges as one of the main complexities that mining companies are facing nowadays. ISO 31000 outlines a framework for risk management for all kinds of organizations, with principles that include integration, a structured and systematic approach, customization, and the best available information, among other principles. Emerging technologies, such as unmanned aerial vehicles (drones), are increasingly being integrated into mining and construction for safety purposes, such as hazard identification, environmental monitoring, surveillance, and mapping (Lööw, 2022). All of this demonstrates the use of emerging technologies in minimizing safety challenges faced by contractors by applying the Risk Management Theory.

EMPIRICAL LITERATURE REVIEW

2.3.1 AUTOMATION IN MINING

M. Long et al. (2024) carried out a study on Equipment and Operations Automation in Mining in Kentucky" revealed that the adoption of autonomous technologies has brought about a huge transformative and technological shift in the mining industry, as they are being applied to repetitive tasks that require speed and precision, which cannot be provided by humans. The main objectives of this particular study are: a) to examine the current technological advancements in automation in the mining sector; b) to examine the applications of autonomous systems and their impacts on enhancing the safety and efficiency of mining operations; and c) to explore the challenges associated with automation and the limitations that hinder the full development of fully autonomous systems. M. Long et al. also outline the benefits of Automated Haul Trucks (AHSs), giving the successful implementation of these AHSs in Western Australia, Rio Tinto, as an example. The benefits include increased productivity; that is, each autonomous truck operates 700 hours more than the old conventional trucks and offers about 15% lower load and haul costs. As proven in this study, the incorporation of robotics, artificial intelligence, and machine learning in mining has improved various aspects of the mining value chain. This has also reduced the occurrence of incidents and accidents by removing human operators from hazardous environments and enabling remote operation. The mining industry can ensure an uninterrupted change towards an automated future by prioritizing human safety and efficient training.

Similarly, **L. Codeco-Contreras, N. Rybak, and M. Hassall (2024)** also **carried out a study in Australia titled** on **the Impacts of Automation in the Mining Industry.** The main objective of this study is to conduct a methodical review of research on the influences of automation from a mining perspective. The study also intended to pinpoint key themes related to automation in mining, such as high-tech advancements, safety enhancements, commercial impacts, and labor force implications. This inquiry uses manual and natural language processing techniques to scrutinize a total of 94 literature papers that dealt with concerns related to the topic, aiding an organized examination of the dataset (Rybak and Hassall, 2023; Smith et al., 2023). Therefore, this study was guided by the following keywords: automation impacts, mining industry, human factors, natural language processing, autonomy, and safety. According to this study, the evolution of automation in the mining sector comprises those connected to the implementation of advanced data and communication technologies, autonomous haulage systems (AHSs), robotics, and automated longwall mining apparatus. The study also shows statistics on the adoption of automation in different countries. Since

2000, innovative ICTs have been implemented by the mining industry to drive enhancements in productivity and safety (Jang and Topal, 2020). Mining companies intend to generate intelligent or smart mines (Shrivastav and Pradhan, 2022). According to Brown et al. (2020), the precarious indicator of the intelligent mine is an ‘unmanned system’ that can function from mining faces, burrowing faces, and risky locations to the entire mine. The introduction of automation into organizations impacts work processes, information flow, employee training (Palka and Stecuła, 2019), and associations in the workstation, habitually among operators and co-workers, administration teams and engineers (Rogers et al., 2019). The articles (Wang et al., 2019; Zhang et al., 2022) focused on the expansion of China’s coal industry and forthcoming trends related to intelligent unmanned mining. This is just one example that demonstrates the benefits of emerging technologies in mines. This methodical evaluation established a comprehensive approach to the implications of introducing automation by studying articles and reports from the last 20 years.

M. Long et al. (2024) also mentioned the use of automation in drilling technologies. The ability of autonomous drill rigs (ADRs) to operate remotely has successfully reduced risks (such as vibration and noise) associated with older drilling techniques. ADRs come with other features such as drill plan handling, void detection, and automatic collaring, which improve accuracy, lower deviation, and enhance drilling consumables.

The technologies that drive ADRs and AHSs are similar in that they consist of wireless systems, control systems, sensors, artificial intelligence, and software. Research carried out by Lodewick showed that automated maintenance systems for conveyor belts make use of vibration analysis to monitor idler rolls and maintain the health of the system. Wang et al.'s research showed that autonomous systems, through the use of variable frequency drives to control the speed and circulatory force of belt motors, can reduce wear. This, therefore, reduces the safety and production risks associated with the wear of the belt.

Due to the numerous challenges associated with underground mining, Xu and Wang applied a longwall shearer path system based on 3D position and dynamic static fusion to collect data. M. Long et al. (2024) clearly outline the various uses of automation in both surface and underground mining for enhanced safety and productivity.

To further elaborate on ADRs, **W. Tianlong, M. Bin, and D. Hongbo (2020)** conducted a study on **Developing Remote Monitoring System for Coal Mine Automated Drilling Rigs**. The authors of this study revealed how a remote monitoring system for automated drill rigs in coal mines was developed. The purpose of the monitoring system is to assess the ADR remotely through sensor measurement, software development, network communication, and other technologies. This system addresses challenges such as incomplete parameter display, inadequate monitoring, and inappropriate maintenance of the ADR. The overall advantage of the monitoring system is that it enhances accuracy in data transmission, through which the ground monitoring role of the ADR is achieved. D. Hangbo et al. (2020) also conducted another research study on electronically controlled automation technology for underground drilling rigs in coal mines. In agreement with the study of W. Tianlong, this study also revealed that drill rigs equipped with functions such as remote control can better improve the automation of the drilling rigs; therefore, it guarantees the safety of personnel and equipment.

2.3.2 HUMAN-LABOR SUBSTITUTION

D. Paredes & D. Flemming-Munozo (2021) carried out a study on Automation and Robotics in Mining. The main objectives of the study focused on the following: a) the rapid increase in the use of robotics and automation in mining; b) the indirect consequences, such as labor markets associated with this change; and c) policy implications, recommendations, and suggestions to consider.

The authors of this research noted the challenge of labor substitution that comes with automation and robotics as an issue of concern, as this can escalate in the future due to reduced costs in technological advancements. According to Australian Mining (2020), the improvements that came with automation during the COVID pandemic included a reduced spread of human contagious risks. Technological advancements have paved the way for mining operations to broaden the use of automation remotely, thereby increasing the use of robotic systems in almost all of its sectors. Due to this, Acemogluand Restrepo (2019) noted that the labor share in mining has decreased from 40% in the mid-1990s to about 20%. This is shown by the use of automated haulage systems (AHSs), automated trucks, and automated drilling rigs (ADRs) that operate remotely and independently of a human operator (as shown in the above literature). The three main impacts of automation mentioned in this study are:

1. Increased substitution of human labor by automation or robotics.

2. The mining sector will have a lower demand for human labor with high-earning salaries.

3. Inequality among employees caused by the shift in salary, as only skilled labor in autonomous operations will be paid more.

These were some of the challenges that came along with autonomous mines, as noted in this study.

However, a study carried out by **Lund, J. Johansson, & J. Lööw (2024)** on The Designers' Perspective on Autonomous Mining Systems and Socio-technology E in Sweden highlighted that despite the advances in technology, many operations still necessitate human oversight. The main objectives of this study are: 1) to examine technology designers' basic norms regarding humans and their relations with the technology they cultivate; 2) to examine the socio-technical consequences of these systems, especially how technology and human factors interrelate in mining environments; and 3) to survey the challenges and opportunities related to the enactment of autonomous systems in mining operations.

The first emphasized area involves the growth of a 5G network resolution for connectivity and locating in underground mining operations. The second emphasis area is on an artificially intelligent (AI) fleet optimization system for interaction between machines, directional support, transportation awareness, situational mindfulness, and fleet supervision for coordination of the entire fleet. The third focus area aims to improve autonomous robotic inspection before and after blasting (carried out by drones). The authors of the study emphasized including a human perspective in the design and development of autonomous systems to adhere to socio-technical systems theory, which encourages a balance between the technological and social subsystems of the entire system. The study also encourages mining operations to focus on optimizing the social subsystem to increase the industry's appeal for retaining skilled workers. The authors encouraged mining operations to have a proactive approach to mitigating potential negative impacts on the workforce. In summary, the outcomes of this research accentuate the necessity of a comprehensive approach to the design of autonomous mining systems, ensuring that technological advancements do not affect or strain the mining workforce.

2.3.3 DRONE SURVEILLANCE IN MINING

J. Shahmoradi et al. (2020) carried out a study in USA on the **Applications of Drone Technology in the Mining Industry**. The key objectives of this study are: a) to produce an understanding of the use and applications of drones in the mining industry; b) to outline the types of drones, specifications, and applications of commercially available drones for mining applications; and c) to outline the design and implementation of drones in underground mining.

The two main applications of drones stated in this article are conducting quick inspections in emergency and hazard identification situations or examining and unclogging blocked box holes and ore passes. J. Shahmoradi et al. outline the uses of drone technology in surface and underground mining, also showing how drones are being used to avert challenges faced in the mining sector, e.g., mapping engineering and in remote locations.

The study also defined the different types of drones used in surface mining and their features, such as their model, wingspan (mm), length (mm), weight (g), endurance (min), and payload (g). The two types of drones specifically stated were the multi-rotor drone and the fixed-wing drone. The application of drones in underground mining was mentioned to be somewhat limited due to the challenges associated with it. However, some of the applications of drone technology in underground mining mentioned include surface roughness mapping, rock mass stability analysis, ventilation modeling, hazardous gas detection, and leakage monitoring. Shahmoradi et al. also mention the types of drones used in underground mining and their features as well. The types of drones specified are the helium gas balloon, octo-copter, and quadcopter (for underground operations). In the case of abandoned mines, the multi-rotor and fixed-wing drones are the ones mainly used.

Biographers of this research also went further to outline the types of sensors used in mining drone technology, which include infrared sensors, ultrasonic sensors, red-green-blue (RGB) sensors, stereo cameras, laser range finders, ultra-wideband radar, hyperspectral sensors, magnetic sensors, visible and near-infrared spectral range (VNIR), and air quality sensors. In conclusion, drone technology is now being applied in countless ways in the mining industry for enhanced safety and health. This can involve emergency surveillance or quick inspection checks around the mine. This demonstrates the use of drone technology in emergency surveillance. This is also in correspondence with "Mine Closure Surveillance and Feasibility of UAV–AI–MR Technology: A Review Study" carried out in Australia (M. Samaei et al., 2024).

The main objectives of this particular study were to assess the role of unmanned aerial vehicles (UAVs) in mine closure, as well as to explore sensor technology, artificial intelligence (AI), and mixed reality (MR) applications. This is because the concern for mine site closure and rehabilitation has now risen to become a global challenge and public concern, which is threatening sustainable mining practices. This paper, therefore, studies modern UAVs, AI, and MR applications in mine recuperation to determine the existing UAV setups and sensors used for monitoring mine closure.

Mine site closure is described as the process of reinstating damaged sites to their preliminary states of efficiency and self-sufficiency while identifying the site’s favorable uses. To achieve all this, all-inclusive management is required, which can be difficult without monitoring and measurement. Characteristically, three remote sensing methods—satellites, crewed aircraft, and unmanned aerial vehicles (UAVs)—are used for capturing high-resolution photographs of massive areas. This, therefore, proves that the development and application of fully autonomous and remotely controlled systems are vital for mine closure and rehabilitation projects. The authors showed and explained how sensing technologies, mixed reality (MR), emerging reality, and UAVs are being applied for mine rehabilitation monitoring, planning, training, and management purposes. Data obtained from UAVs powered by AI can be used to generate MR models to visualize and strategize mining operations, such as detecting the best location for a mine, measuring the impact of a new mine on the environment, and suggesting plans for mine closure and recovery. Padró et al. (2019) also carried out an investigation on the restoration of an open-pit mine of less than 10 hectares using a small, lightweight rotary-wing UAV equipped with sensors that have a spatial resolution of 9 cm. This study showed how the use of automated batch processes reduces fieldwork time compared to traditional methods. The authors also demonstrated how UAVs are used in hazard identification by referencing a study carried out by Nguyen et al. that proposed an air quality monitoring system and spatial analysis using UAVs. They combined gas and dust sensors into the UAV and used various spatial interpolation methods to determine air concentration levels of CO, SO2, PM2.5, and CO2 in the atmosphere of open-pit coal mines. The study also shows how different types of sensors are used for UAV-based mine surveillance. The different types of sensors illustrated in the study were the visual sensor, acoustic sensor, thermal sensor, chemical sensor, light detection and ranging (LiDAR) sensor, red-green-blue sensors, and multi-spectral sensors. UAV/drone technology is also being applied in data acquisition, which is, however, affected by meteorological conditions. Sensors are an economical and efficient way of accomplishing results, including industrial process upgrading, merchandise enhancement, equipment/machinery monitoring, quality control, employee productivity improvement, and employee health and safety.

Similarly, **J. Duarte F. Rodrigues & J. Castelo (2022)** also carried out a study on the **Applications of sensors in the Mining Industry** in **Portugal.** The main objectives of this study are therefore: a) to explore how sensing technologies are being integrated into the mining industry; b) to also explore how sensors could enhance safety and identify the associated challenges; c) to recognize steps such as prototype development, trial phases, and full-scale implementation of these machineries in the industry. This review initially outlines the overall framework of Industry 4.0, which is made up of four layers, namely physical (devices), network (related to connectivity), big data (how the data is kept), and application. The authors go on to explain the different roles of sensing technologies, stating that wireless network systems (WNS) are among the most common means of attaining the potential and objectives of the first layer due to their flexibility. The authors of this study analyzed 29 papers (which consisted of different applications of sensors in several fields such as safety, management, and localization) using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to assess the challenges of sensor technology in mining, the applications of sensor technology in both underground and surface mining, and to emphasize the necessity for enhancements in data allocation mechanisms, real-time monitoring, and automation in mining operations. An insight into the sensors' applicability and potential was provided in the form of a table showing sensor data in terms of type, connectivity, collected data, system setup, and implementation status. The first step of the study was to analyze the country of origin of each article, which showed that the most represented country was China. The next step was to classify each study according to its context (mine or quarry) and setting type (underground or surface). The results showed that the vast majority of studies took place in a mining setting, and the assumption for this was that mining commodities require a more complex process, both in terms of exploitation and processing. The study demonstrated how sensing technologies are applied in underground mines, which include deformation tunnel monitoring, performance of underground mapping measurements, measurement of transport times, and monitoring of air quality.

2.3.4 THE EFFECTIVENESS OF NEW TECHNOLOGIES

Emerging technologies such as drone surveillance and automation are being highly effective in separating human workforce from hazardous operations thereby mitigation risks.

C. Cacciutolo et al. (2024) clearly explain the use of sensor technologies for safety monitoring in mine tailing storage facilities: solutions in the industry 4.0 era. This research was carried out in Chile. The subject of tailing dam failures in mines has been of major concern; for example, the TSF dam failure in Jaggersfontein, South Africa, in 2022 and other TSF failures emphasized in this study have led to many investigations aimed at finding out the causes of these dam failures. Therefore, the main objective of this study is not only to identify the causes of these tailing dam failures but also to:

a) Research on how industry 4.0 technologies such as the Internet of Things can be used to recover safety in mine tailings b) To introduce and offer better and value-added sensing systems for proper risk mitigation, the WOS (Web of Science) and Scopus were used for the systematic review of 194 articles related to this study. First and second filter segregations left only 52 articles out of the 194 for analysis. All the studies displayed the evolution of sensors for monitoring trends in TSFs, thereby thwarting accidents and disasters. The main applications of sensors in TSF monitoring in this study were remote measurements (with 35 mentions in all the articles) and site measurements (with 5 mentions). The authors also highlighted the diverse types of sensors, stating that water level sensors (piezometers) had the most mentions (8 mentions), followed by pressure sensors with 6 mentions and displacement sensors with 5 mentions. Ninety percent of the articles discussed automatic applications with real-time data collection when studying the type of operation of sensor systems. Concerning engineering disciplines, the studies showed that geo-technics is the most mentioned (with 15% mentions) and this shows that structured stability aspects are an important use of sensor systems in mining. Near real time systems are being used to inform responsible personnel when TSF thresholds are exceeded. The study also shows the use of geotechnical data loggers to record trends in the physical and chemical bounds monitored.

The use of Sensor technology and machine learning is of great benefit not only TSF monitoring but to also monitor ear related medical conditions and treatments.

L. Ntlhakana et al. (2021) conducted a study on **the Influence of Data Sharing practices on Occupational Hearing Loss for Platinum Miners in South Africa.** The main objective of this study, carried out in South Africa, was to determine how data related to occupational hearing loss is transferred within the mining sector and to learn about the challenges and restrictions in these data-sharing practices. The findings of the study aim to provide solutions that focus on refining occupational health issues (particularly noise-induced occupational hearing loss, or ONIHL) in the mining industry. Machine learning systems are an essential part of managing and storing HCP big data, which depends on good quality data, accurate and consistent data updates, and ethical principles. The authors of this study highlighted the importance of stronger monitoring and accountability systems to foster compliance with HCP and data management among all mines.

Applications of Unmanned Aerial Vehicles by S. Park and Y. Choi (2020) in Korea

This revision intends to analyze educational papers on the uses of UAVs in mining by sorting the mining process into three stages, namely exploration, exploitation, and reclamation. It also highlights the benefits associated with UAV use in mining operations and proposes upcoming tips for research in the application of UAVs in the mining sector. Another objective of this study was to pinpoint the challenges and restrictions associated with UAV operation in the mining sector. In the first mentioned stage, which is the exploration phase, the available literature was reviewed after being divided into two categories according to the type of data that could be obtained by UAVs: geological and organizational analysis via remote sensing and aerial geophysical exploration. The type of sensors mentioned for geological and structural analysis via remote sensing is the fixed-wing sensor, while for aerial geophysical surveys, the rotary-wing sensor is used. Jakob et al. established a new toolbox for treating hyper spectral data gained by drones and assessed whether it could be functional to geological surveys.

The applications of UAVs in the exploration phase include the use of UAVs for topographic surveying at open-pit and underground mines, rock slope analysis, and work environment analysis. Topographic surveying involves costly equipment (total stations and terrestrial laser scanners), but with the use of UAVs, rapid surveying of larger areas can occur within a reasonable budget. Lee and Choi carried out topographic surveys of various open-pit mines using rotary and fixed-wing UAVs. Another application of UAVs in the exploration stage is for rock slope analyses, as well as the stability and discontinuity analysis of rock slopes that are challenging to access directly, and for the lithological arrangement of rock masses. Beretta et al. categorized rocks on the gradients of open-pit mines using UAV photogrammetry and machine learning. In addition to taking aerial photographs, UAVs fitted with thermal and dust sensors perform tasks related to monitoring or analysis of the working environments and workers in mines.

The applications of UAVs in the final mining phase, which is the Mine Reclamation Phase, include forest and vegetation restoration, groundwater level restoration, and environmental monitoring in conjunction with mine closure. According to the type of refurbishment work executed by applying the UAV system, the existing literature was classified into soil and water pollution monitoring, ecological renovation monitoring, and ground sinking monitoring. For safety purposes, it is greatly challenging for humans to explore and monitor areas where ground sinking occurs; thus, the importance of using UAVs is increasing.

2.3.5 CHALLENGES IN THE USE OF NEW TECHNOLOGIES

Regardless of the numerous benefits (mentioned above) that come with the use of automation and drones, the complete implementation of these technologies still faces many hurdles. The study carried out by S. Park and Y. Choi (2020) in Korea on the Applications of Unmanned Aerial Vehicles in Mining from Exploration to Reclamation revealed that one of the challenges associated with drone technology is related to technical limitations. Issues such as GPS signal loss are a major concern in underground mines. The study also highlighted the issue of high initial investment costs, which is a significant concern because many small-scale mining companies struggle to afford these technologies. However, contradicting this issue, a cost-benefit analysis by Miller & Zhang (2022) recognized that while the initial investments in automation and drone technology are high, there are long-term benefits due to reduced insurance costs and lower compensation costs. Similarly, **J. Duarte F. Rodrigues & J. Castelo., 2022 study on the Applications of sensing technologies** revealed that the mining industry as it is one of the most hazardous economic sectors is not exempted to these issues and this makes its technical issues more multifaceted due to its vibrant nature. The mining sector should therefore make use of the tools presently existing so as to generate productions that are not only cost effective but also offer safe working environment. Raj et al., 2019 also mentions financial constraints as a major obstacle especially concerning the high upfront costs associated with technology acquisition and maintenance. According to (Mokgatla, 2022; Mokganya et al., 2024), organizational resistance to change plays a major role which may lead to innovation resistant safety cultures. In contractor-managed areas, limited leadership support, a lack of formalized change management, and fear of job displacement contribute to reluctance toward adopting new technologies. Additionally, the mining sector is also affected by a persistent gap in expertise insight on the implementation of these new technologies therefore comprehensive training and upskilling is a necessity (Statista, 2020). Lastly, the increasing digitization of mining operations has given a rise to cybersecurity concerns. As more systems become interconnected, the risk of cyberattacks grows, especially in operations where IT governance is weak or fragmented (Buthelezi, 2024).

2.4 RESEARCH GAPS

Emerging technologies have been widely used and researched; however, there is limited research on the long-term impacts that come with these technologies, especially regarding the reduced human oversight that is posed as a threat by these technologies. There is, therefore, a need for the drafting of policies that balance the issue of technological advancements with the human workforce. Further research on this should also provide more insight into the cyber threats associated with these technologies and how to reduce them, which will, in turn, enhance the efficiency of these technologies. Even with the numerous technological advancements related to monitoring the physical and chemical stability of TSFs, several mining organizations are still characterized by low-level monitoring techniques. Progress in AI (artificial intelligence), ML (machine learning), CC (cloud computing), and data analytics will assist and promote a pre-emptive approach to TSF prevention. Due to online real-time monitoring of TSF there would be boosted visualization of chemical and physical stability indices. Mining entities should establish a permanent technological surveillance program so as to achieve a smart monitoring model for its TSFs. Adoption of industry 4.0 technologies requires support from all interested parties and stakeholders in the mining ecosystem.

2.5 CONCLUSION

This chapter mainly focuses on revising the role of automation and drone technology in hazard prevention and risk mitigation by reviewing the existing literature pertaining to this particular subject. The literature outlines the benefits that come with the implementation of drone technology and automation in mining systems, as well as the challenges that arise prior to or after implementation. Research gaps indicate the necessity for further study on the long-term impacts of these technologies and how to reduce the challenges associated with them.

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

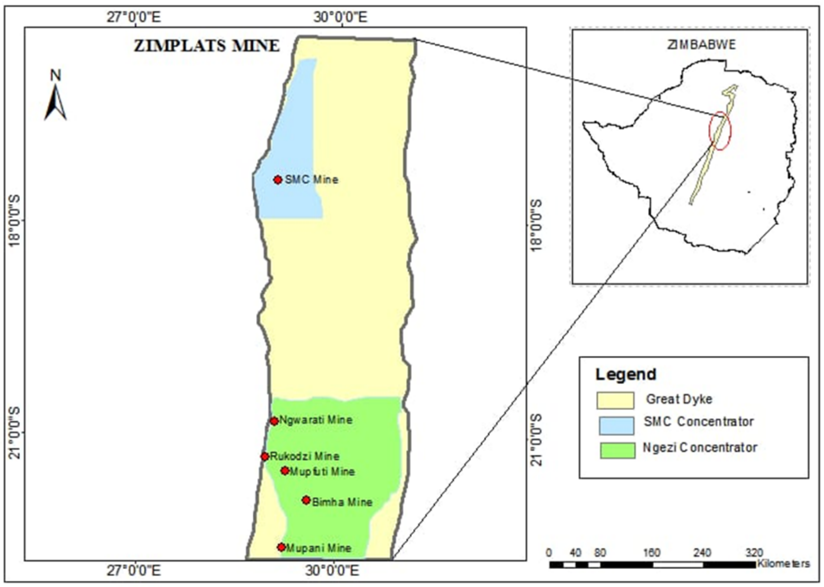
This chapter outlines the research methodology used to investigate the impact of automation and drone technology on hazard prevention and risk mitigation in the mining sector. The research methodology adheres to the Saunders et al. research onion framework, which entails different layers, including research philosophy, approach, research design (including the strategy and methodological choices), data collection methods, and the ethical considerations of the particular study. This chapter will also show the study area.

3.2 RESEARCH PHILOSOPHY

The study adopted a pragmatist research philosophy, which turned out to be the most appropriate since it involves both qualitative and quantitative data. A pragmatist research philosophy allows for flexibility in combining different research methods to provide an in-depth understanding of the research problem (Y. Shan, 2022). The main objectives of this study focus on evaluating the effectiveness of drone surveillance and automation using assessable indicators (quantitative) and understanding the challenges through expert insights (qualitative); thus, pragmatism became the most fitting philosophy. The pragmatist research philosophy accepts concepts only if they are supported by action and defined by their pragmatic use in ongoing experience (B. Dube, D. Nkomo, & M. Thokweng, 2024).

3.2.1 STUDY AREA

The investigation of this research included a case study strategy, which was carried out at ZIMPLATS mines and processes platinum groups. It executes its operations at Selous (-18.03613, 30.42888°) in Chegutu and at Ngezi (-18.66611°, 30.354722°) in the Kadoma districts of Mashonaland province, Zimbabwe (Fig. 3.1). The Ngezi site, located on the Great Dyke, contains the platinum group metals (platinum, palladium, rhodium, nickel, cobalt, gold, and others) (Zimplats Intranet, 2021). Contract workers are hired for plant maintenance at both the Ngezi and Selous (SMC) sites. The Selous Metallurgical Complex is situated 77 kilometers north of the underground (Ngezi), and it currently comprises a concentrator and a smelter, which has recently been expanded (Zimplats Intranet, 2024).



(Fig 3.1)

3.3 RESEARCH DESIGN

The research was carried out using mixed methods. The mixed method strategy incorporates both qualitative and quantitative methods (Campbell et al., 2020). The research assumed a cross-sectional survey design, which involves collecting data at a single point in time rather than over a prolonged period (M. Chennai et al., 2022).

3.3.1 RESEARCH STRATEGY

To attain the objectives of this research, the study shall make use of a case study strategy (Zimplats) combined with survey research. The case study aims to focus on hazard detection and risk mitigation through drone surveillance and automation, which is being achieved and implemented as of the current date at the mine. The survey research entails gathering data through questionnaires and interviews from the mine's competent personnel on the issue at hand, as well as from the contracted workers.

3.3.2 RESEARCH CHOICES

The researcher made adopted a concurrent mixed methods design, where qualitative and quantitative data were collected in unison.

3.3.3 RESEARCH APPROACH

The study adopted a mixed-methods research approach, as it is suitable for assessable data and provides an in-depth insight into challenges and user experiences (H. Taherdoost, 2022). The quantitative aspect of the research involves collecting numerical data on accident rates and risk mitigation efficiency before and after automation and drone surveillance. Questionnaires and interviews, which focused on understanding operational, financial, and safety challenges associated with the adoption of drone surveillance and automation, were conducted for this particular research. The researcher gathered insights from miners, engineers, and safety officers on their experiences with drones and automation and how these have aided in hazard detection and risk mitigation.

3.3.3.1 TRIANGULATION

Triangulation is a research method used to improve the trustworthiness and rationality of study findings through the use of various data sources, methods, or views (Bans-Akutey, A., & Tiimub, B. M, 2021). For this particular research, methodical triangulation was used, whereby questionnaires were used together with face-to-face interviews. This ensured the credibility and validity of the research findings.

3.4 SAMPLING TECHNIQUES

For this particular study, purposive sampling was used to select individuals who have expert knowledge in mine safety automation and drone technology. The logic behind using a purposive sampling technique is that it best suits the sample to the specific aims and objectives of the research, thereby enhancing the accuracy of the data and results of expert insight (S. Campbell et al., 2020).

The focus was mainly on solicitation rich, relevant and informed insights from mine managers, safety officers, contractors and technology operators. Yamane’s Formula was used for sample size determination (Uakarn, C., Chaokromthong, K., & Sintao, N, .2021)

$n = N / (1 + N * e^2)$

Where: n= required sample size; N = total population size; e = margin of error (level of precision); Confidence level = typically 95%; Z = Z-score corresponding to the confidence level; p = estimated proportion of the population with the attribute (default = 0.5 for maximum variability) (Uakarn, C., Chaokromthong, K., & Sintao, N, .2021).

For this particular study:

N = 40 (number of relevant staff in the mine's processing and underground mining departments)

e = 0.10 (10% is acceptable for targeted samples)

Confidence level = 95% (Z = 1.96)

Therefore: $n = 40/ (1+40 * 0.10^2) = 40/ (1+0.4) = 40/1.4= 28.57$. Rounded off the sample size became 29. Of the 29 respondents expected to turn up for answering the Likert scale questionnaire, 25 were available and all 25 answered fully.

The recruitment process to identify eligible participants involved liaising with the mine's HR department, sending invitation letters and participant information sheets explaining the study's purpose, confidentiality, and voluntary nature. Mensah et al. (2021) carried out a study on mine safety in Ghana which combined purposive and convenience sampling in a mixed-method study.

3.5 RESEARCH INSTRUMENTS

3.5.1 QUESTIONNAIRE

This is a systematic way of collecting data from a group of individuals through structured questions pertaining to a particular subject (S. Blatchford, 2020). The use of questionnaires minimizes bias by allowing the researcher to uniformly pose identical topics to the targeted population rather than having them receive the same question in various manners (Kumari et al., 2020). The major setback with questionnaires is that they are affected by question understanding and interpretation by the respondent; hence, the questionnaires were also administered in vernacular for better clarity. The questionnaire comprised questions that were concerned with the impact of automation and drone technology in hazard detection.

3.5.1.2 LIKERT SCALE QUESTIONNAIRE

A structured questionnaire that includes Likert scale questions was distributed to the target population (mining engineers, safety officers, drone operators, and contract workers at Zimplats). The Likert Scale is a rating scale that is used to measure opinions, attitudes, and perceptions toward a particular aspect (H. Taherdoost, 2019). It is essentially a quantitative approach, with the commonly used Likert scales being the 5-point Likert scale and the 7-point Likert scale (A. Jebb, V. Ng, & L. Tay, 2021). The purpose of including the Likert scale is to measure the perceptions of drone automation effectiveness in the mine. For this particular study, a 5-point Likert scale ranging from “Strongly disagree "(1) to "Strongly agree “(5). The main target of the questionnaire is on the insights of technology effectiveness and the challenges associated.

3.5.2 ACCIDENT AND ICIDENT RECORDS

The mine's historical accident reports are to be collected to analyze the trends in accident rates, response times, and injury severity, in order to provide an in-depth, quantifiable comparison (using trend analysis) of accident rates before and after the implementation of automation and drone surveillance.

3.5.3 INTERVIEWS

Semi structured interviews were conducted with mine managers, engineers, contractors and Sheq officers at the mine so as to get deeper insights and personal experiences on the impact of automation and drone technology in the mine. According to Showkat et.al. 2017 an interview provides mere comprehensive and circumstantial information as compared to collection methods like the surveys. The interviews carried out with key stakeholders provides an in-depth insight into the benefits and challenges of automation from the perspective of miners, engineers and managers. It comprised of both open ended and close ended questions.

3.6 VALIDITY AND RELIABILITY

Validity refers to the extent to which particular research accurately measures what it intends to measure while reliability indicates the consistency and stability of the research results. In other words, Validity refers to accuracy whereas reliability refers to consistency (Coleman, P., 2022). A reliable or accurate research gives consistent findings that can be reproduced under the same conditions thereby improving confidence in the results (Coleman, P., 2022)

Content Validity was ensured by seeking expert guidance for the development of questionnaire items. Construct validity was intensified by harmonizing questionnaire items with theoretical and practical constructs of hazard prevention and risk mitigation.

3.7 DATA ANALYSIS

SPSS and Microsoft Excel applications were used for statistical analysis of the comprehensive data (William, 2022). The software allows for the creation of graphs and other methods to provide a visual representation of descriptive statistics methods, such as the chi-square test (Elsayed, 2022), which can be used to show the relationship between automation adoption and safety improvements. For the Likert scale rating, the responses were analyzed and summarized using mean scores, standard deviations, and frequency distributions to determine the overall sentiment regarding the impact of drone surveillance and automation on mining safety. The software was also used to analyze the Likert scale data through descriptive statistics and to visualize the data using charts.

Information gathered from interviews was analyzed using thematic analysis. Thematic analysis (TA) is a qualitative data analysis method used for identifying and interpreting common themes (M. Kiger, L. Varpio, 2020). In the particular context pertaining to this study, thematic analysis was carried out to categorize the interview responses into key themes such as cost/financial challenges and inadequate training personnel constraints. C.R. Lochmiller (2022) discusses an approach for carrying out thematic analysis for qualitative data. However, thematic analysis depends on the researcher's judgment and is somewhat time-consuming (M. Kiger, L. Varpio, 2020).

3.8 ETHICAL CONSIDERATIONS

According to Melinda Dooly (2017), qualitative research often requires researchers to be ethical due to the fact that the design of the research involves human contributions. The research ethics statement extracted from the Grup De Recerca en Ensenyament i Interacció Plurilingües (GRUEP) outlines guidelines and highlights where ethics should be applied when carrying out qualitative research. The following ethics were followed during the course of the research: seeking permission to conduct the study from the University (Bindura University of Science Education) Department of Environmental Science; informing participants about the purpose of the research and their right to withdraw at any moment if they feel their rights are being infringed (A. Josephine, 2021); the principle of confidentiality, which makes it mandatory for the researcher to keep the participants' responses and identity a secret (HJ. Hwang, 2023); and the ethical considerations concerning data security, where all the collected data was securely stored and reserved for academic purposes only (A. Karate., 2021).

3.9 SUMMARY

This chapter comprises the research methods that were endorsed in the study. By adopting a pragmatic research philosophy, which allows for a mixed methods approach and also using a case study strategy, the researcher carried out an in-depth analysis of both the effects and challenges associated with the adoption of drone surveillance and automation in mining. Careful consideration and compliance were given to research ethics to promote justifiable and responsible conduct. The next chapter will present the findings and analysis based on the collected data.

CHAPTER 4: PRESENTATION OF RESULTS

4. 1 INTRODUCTION

This chapter outlines at the presentation of the results in relation to the data findings of this particular study. The study objectives were analyzed individually and these namely are to assess the effectiveness of new technologies in hazard detection and risk mitigation and to assess the challenges associated with the adoption of new technologies in the mining sector. The findings of this research encompass of responses from questionnaires, interview data analysis historical mine data showing accident trends before and after technology implementation. This includes descriptive statistics, reliability test, comparative analysis amongst groups and also visual presentations trends related to historical accident trends before and after technology implementation.

4.2 DEMOGRAHIC INFORMATION OF RESPONDENTS

4.2.1 JOB ROLE

specify your job role

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	mine manager	3	12.0	12.0	12.0
	engineer	7	28.0	28.0	40.0
	contractor	11	44.0	44.0	84.0
	safety officer	4	16.0	16.0	100.0

	Total	25	100.0	100.0	

Table 4.2.1 shows the demographics of respondents according to their job roles. As shown in the table above, the total number of the population who respondent fully was 25. Contractors made up the larger percentage of the respondents' population with a total percentage of 44%. Engineers made up 28% of the respondents' population: safety officers consisted 16% and mine managers making the smaller percentage of the population with 12%. These demographics show the percentage distribution of different job roles which made up the respondents of this study.

4.2.2 YEARS OF WORKING EXPERIENCE

years of work experience in the mining sector

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	less than 5 years	7	28.0	28.0	28.0
	5-10 years	11	44.0	44.0	72.0
	11-15 years	3	12.0	12.0	84.0
	more than 15 years	4	16.0	16.0	100.0
	Total	25	100.0	100.0	

Table 4.2.2 shows the years of working experience of the respondents. As shown in the table, the majority of the respondents ranged between the 5 to 10 years of working experience. Respondents with less than 5 years working experience made up 28% of the respondents' population; those with 5 to 10 years made up 44% of the respondents' population; those with 11 to 15 years working experience made up 12% of the respondents' population and those with more than 15 years of working experience made up the remaining 16% of the population.

4.2.3 GENDER

specify your gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	male	18	72.0	72.0	72.0
	female	7	28.0	28.0	100.0
	Total	25	100.0	100.0	

Table 4.2.3 shows the distribution of respondents according to their gender. Males dominated the larger percentage of the population with 72%. Females made up the remaining 28% of the population. This generally shows gender distribution in the mining sector with males making up the larger percentage.

4.3 TECHNOLOGIES CURRENTLY USED AT THE MINE

Technology	Department	Purpose
Automated Drill Rigs and Automated Haulage Trucks	Drilling	Removes human operators from harmful operations such as unstable rocky areas.
Real time monitoring systems	Operations	Used in the central control room to track worker location and activities
Wearable detection sensors	Processing	To monitor worker location, fatigue, heat stress and emergency alerting
Drones	Loss Control	Surveillance and monitoring in risky inaccessible areas

4.4 EFFECTIVENESS OF NEW TECHNOLOGIES IN RISK MITIGATION

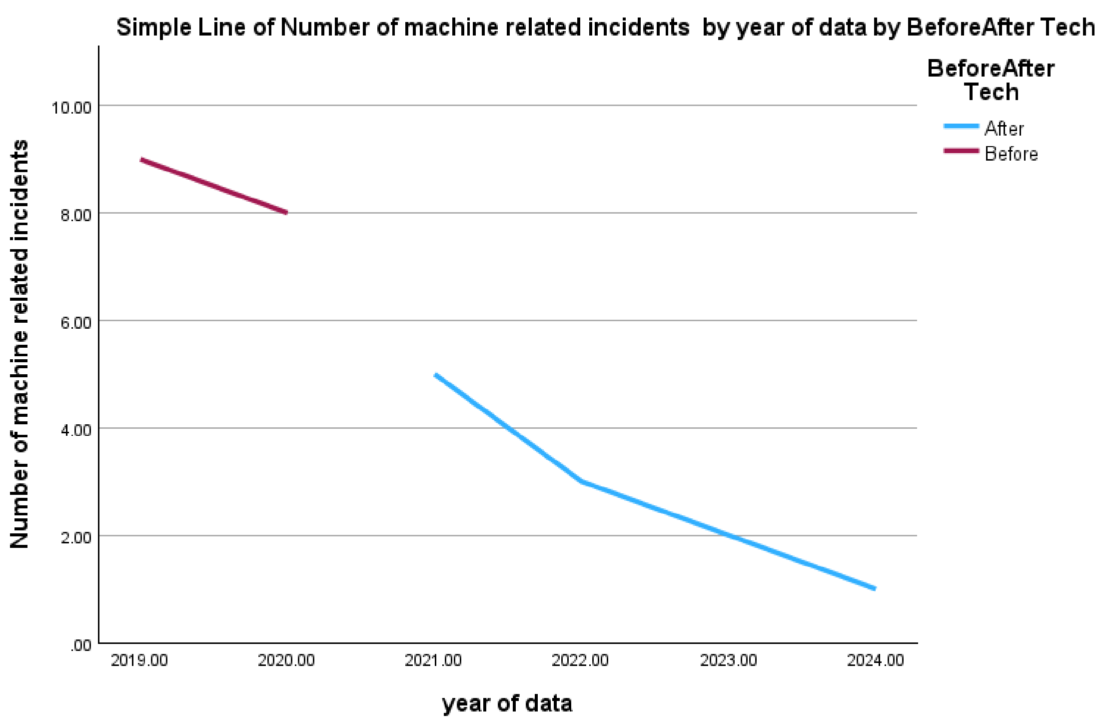
4.4.1 AUTOMATED DRILL RIGS IN THE DRILLING DEPARTMENT

Descriptives

	Before\After Tech			Statistic	Std. Error
Number of machine related incidents	After	Mean		2.7500	.85391
		95% Confidence Interval for Mean	Lower Bound	.0325	
			Upper Bound	5.4675	
		5% Trimmed Mean		2.7222	
		Median		2.5000	
		Variance		2.917	
		Std. Deviation		1.70783	
		Minimum		1.00	
		Maximum		5.00	
		Range		4.00	
		Interquartile Range		3.25	
		Skewness		.753	1.014
		Kurtosis		.343	2.619
	Before	Mean		8.5000	.50000
		95% Confidence Interval for Mean	Lower Bound	2.1469	
			Upper Bound	14.8531	
		5% Trimmed Mean		.	
		Median		8.5000	
		Variance		.500	
		Std. Deviation		.70711	

		Minimum	8.00	
		Maximum	9.00	
		Range	1.00	
		Interquartile Range	.	
		Skewness	.	.
		Kurtosis	.	.

The Descriptive Statistics table shown above shows that the mean number of machine related incidents in the drilling department decreased from Mean = 8.500; Std = 0.70711 before technology was implemented (automated drill rigs) to Mean = 2.7500; Std = 1.70783 after the implementation of technology in the drilling department. This reduction in the number of machine related incidents clearly shows the technology's effectiveness in hazard reduction and risk mitigation.



The graph shows a steady decrease in the number of machine related incidents in the years 2019 and 2020 before the implementation of automated drill rigs (marked by a pink line). The graph also shows a sharper decrease from the year automated drill rigs were first implemented (2021 to 2024). This shows the new technology' effectiveness.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Machine Related Incidents (Before)	8.50	4	.577	.289
	Machine Related Incidents (After)	2.75	4	1.708	.854

The average number of machine related incidents went down from 8.50 before the use of automated drill rigs for drilling to 2.75 indicating the improvement on safer after technology was implemented. A paired T- test revealed a p value = 0.003 showing that the reduction in incidents after implementation of automated drill rigs in the drilling department is statistically significant since p= 0.003 < 0.05

Paired Samples Effect Sizes

			Standardizer[a]	Point Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper
Pair 1	Machine Related Incidents (Before) - Machine Related Incidents (After)	Cohen's d	1.708	3.367	.664	6.095
		Hedges' correction	2.360	2.436	.481	4.410

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.
Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

The table shows the Cohen's d = 3.367 and this reflects the implementation of automated drill rigs has had a strong impact since d>0.8. A Cohen's d measures the magnitude of change between two means therefore in paired samples, the mean difference shows the effect size between two related groups. The 95% confidence interval (0.664 to 6.095) shows that the true effect is considerable.

LIKERT DATA

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Automated drill rigs have effectively reduced direct human exposure in harmful working areas	25	3.00	4.00	3.7600	.43589
Valid N (listwise)	25				

The above table shows the Likert Scale questionnaire response for the effectiveness of automated drill rigs. Generally responses were neutral with a Mean =3.7600; Standard deviation=0.43589. The mean score of 3.7600 implies that respondents leaned towards agreement however without a strong consensus. This was due to difference in perceived effectiveness across different job roles.

4.4.1.2 QUALITATIVE INSIGHTS

Interviewed engineers and drill operators highlighted increased drilling precision, increased productivity and safety as the main key themes. One manager went on to mention that automated drill rigs have minimized errors and redundancy thereby reducing consumable costs. However, contracted employees mentioned the issue of being replaced by more tech-advanced personnel and therefore displayed resistance to the technology.

4.4.2 REAL TIME MONITORING IN THE OPERATIONS DEPARTMENT.

Descriptives

	Before/After Tech			Statistic	Std. Error
Average response time in minutes	After	Mean		9.0000	1.82574
		95% Confidence Interval for Mean	Lower Bound	3.1897	
			Upper Bound	14.8103	
		5% Trimmed Mean		9.0000	

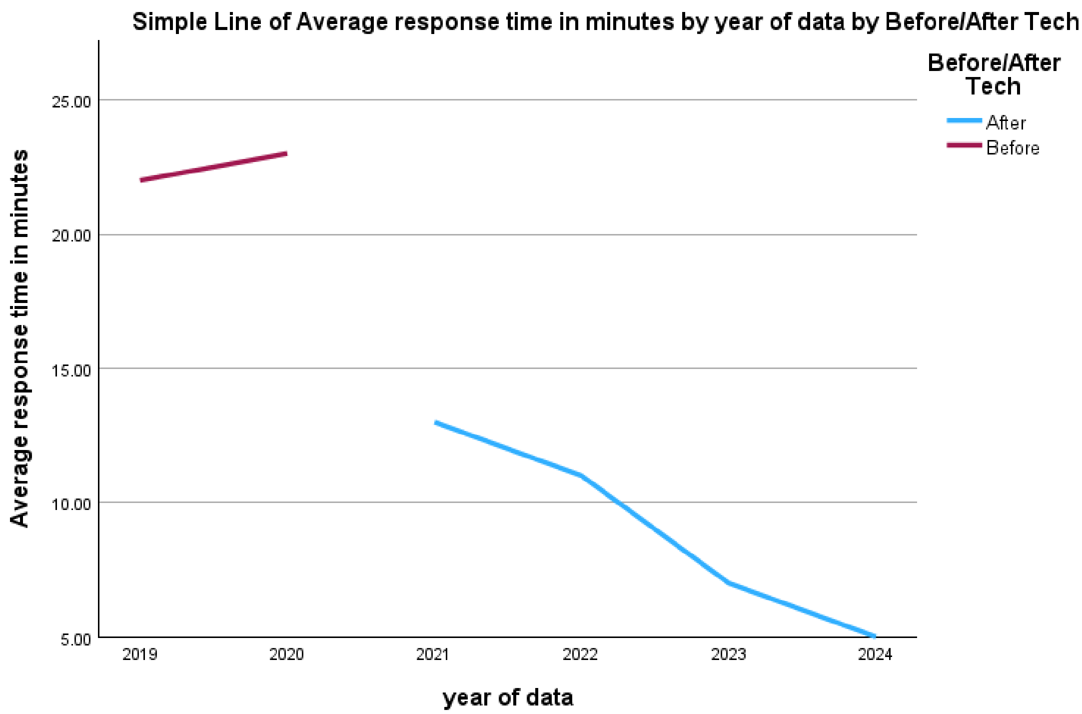
		Median		9.0000	
		Variance		13.333	
		Std. Deviation		3.65148	
		Minimum		5.00	
		Maximum		13.00	
		Range		8.00	
		Interquartile Range		7.00	
		Skewness		.000	1.014
		Kurtosis		-3.300	2.619
	Before	Mean		22.5000	.50000
		95% Confidence Interval for Mean	Lower Bound	16.1469	
			Upper Bound	28.8531	
		5% Trimmed Mean		.	
		Median		22.5000	
		Variance		.500	
		Std. Deviation		.70711	
		Minimum		22.00	
		Maximum		23.00	
		Range		1.00	
		Interquartile Range		.	
		Skewness		.	.
		Kurtosis		.	.
Number of LTIs	After	Mean		1.7500	.85391

recorded		95% Confidence Interval for Mean	Lower Bound	-.9675	
			Upper Bound	4.4675	
		5% Trimmed Mean		1.7222	
		Median		1.5000	
		Variance		2.917	
		Std. Deviation		1.70783	
		Minimum		.00	
		Maximum		4.00	
		Range		4.00	
		Interquartile Range		3.25	
		Skewness		.753	1.014
		Kurtosis		.343	2.619
	Before	Mean		6.5000	.50000
		95% Confidence Interval for Mean	Lower Bound	.1469	
			Upper Bound	12.8531	
		5% Trimmed Mean		.	
		Median		6.5000	
		Variance		.500	
		Std. Deviation		.70711	
		Minimum		6.00	
		Maximum		7.00	
		Range		1.00	

		Interquartile Range	.	
		Skewness	.	.
		Kurtosis	.	.

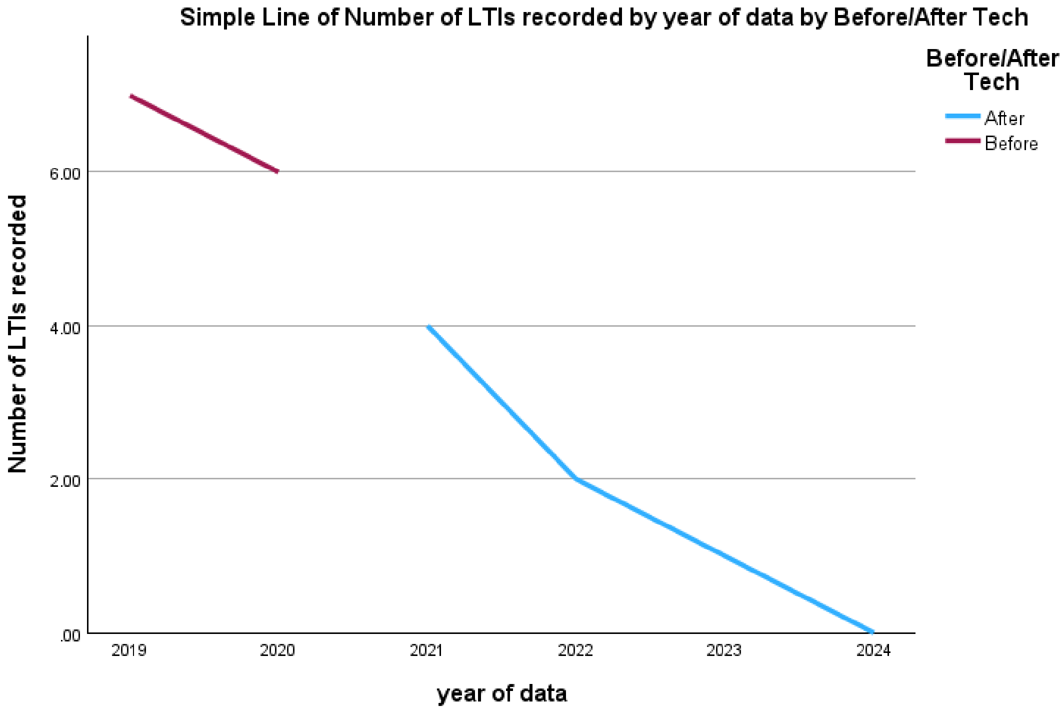
The Descriptive Statistics table shown above shows that the mean time taken to respond to emergencies in the operations department decreased from Mean = 22.500; Std = 0.70711 before technology was implemented (real time monitoring systems) to Mean = 9.0000; Std = 3.65148 after the implementation of real time monitoring systems in the operations department. This reduction in the time taken to respond to emergencies clearly shows the technology's effectiveness in early detection of emergencies and risky situations. The table also shows that the mean number lost time injuries in the operations department decreased from Mean = 6.500; Std = 0.70711 before technology was implemented (real time monitoring systems) to Mean = 1.7500; Std = 1.70783 after the implementation of real time monitoring systems in the operations department. This reduction in the number of Lost Time Injuries clearly shows the technology's effectiveness in early hazard detection before any injuries occur.

Line Graph showing the time taken to respond to emergencies over years



The graph shows a steady increase in the time taken to respond to emergencies in the years 2019 and 2020 before the implementation of time monitoring systems (marked by a pink line). The graph also shows a sharper decrease with relative small fluctuations from the year the technology was first implemented (2021 to 2024). This shows the new technology' effectiveness. The fluctuations represent the challenges which are encountered during implementation and use of real time monitoring systems.

Line Graph showing the number of Lost Time Injuries over years



The graph shows a slow steady decrease in the number of LTIs in the years 2019 and 2020 before the implementation of real time monitoring systems in the operations department (marked by a pink line). The graph also shows a sharper decrease from the year real time monitoring systems were implemented were first implemented (2021 to 2024). This shows the new technology' effectiveness (marked by a blue line).

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Emergency Response Time in minutes (Before)	22.50	4	.577	.289
	Emergency Response Time in minutes (After)	9.00	4	3.651	1.826
Pair 2	Number of LTIs (Before)	6.50	4	.577	.289
	Number of LTIs (After)	1.75	4	1.708	.854

The average time taken in minutes to respond to emergencies went down from 22.50 before the use of real time monitoring systems to 9.00 indicating the improvement on safety after technology was implemented. The average number of Lost Time Injuries went down from 6.50 before the use of real time monitoring systems to 1.75 indicating the improvement on safety after technology was implemented. A paired T- test revealed a p value = 0.001 showing that the reduction in Lost Time Injuries after implementation of real time monitoring systems in the operations department is statistically significant since p= 0.003 < 0.05.

Paired Samples Effect Sizes

			Standardizer[a]	Point Estimate	95% Confidence Interval	
					Lower	Upper
Pair 1	Emergency Response Time in minutes (Before) - Emergency Response Time in minutes (After)	Cohen's d	3.697	3.652	.757	6.586
		Hedges' correction	5.109	2.642	.548	4.766
Pair 2	Number of LTIs (Before) - Number of LTIs (After)	Cohen's d	1.708	2.781	.464	5.091
		Hedges' correction	2.360	2.013	.336	3.684

a. The denominator used in estimating the effect sizes.

Cohen's d uses the sample standard deviation of the mean difference.

Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

The table shows the Cohen's d = 3.652 for emergency response time in minutes and a Cohen's d= 2.781 for the number of LTIs. This reflects the implementation of real time monitoring systems has had a strong impact in reducing the time taken to attend to emergency situations and also reducing the number of Lost Time Injuries since both d>0.8. A Cohen's d measures the magnitude of change between two means therefore in paired samples, the mean difference shows the effect size between two related groups.

<u>LIKERT DATA</u>

	N	Minimum	Maximum	Mean	Std. Deviation
The use of real time monitoring systems (gas sensors, surveillance cameras) has enhanced hazard detection in the mine	25	4.00	5.00	4.5200	.50990
Valid N (listwise)	25				

The above table shows the Likert Scale questionnaire response for the effectiveness of real time monitoring systems in hazard detection. Generally responses showed strong agreement with a Mean =4.5200; Standard deviation=0.50990. The mean score of 4.5200 implies that respondents strongly leaned towards agreement with a strong consensus

4.4.2.2 QUALITATIVE INSIGHTS

Interviewed engineers and drone operators highlighted increased production tracking, increased safety monitoring, and improved fleet and traffic management as the main key themes. Contractors went on to mention improved and safer working conditions due to continuous environmental monitoring. However, mine managers mentioned connectivity and signal issues as major challenges slowing down the full effectiveness of real time monitoring systems.

4.4.3 WEARABLE SENSORS IN THE PROCESSING DEPARTMENT

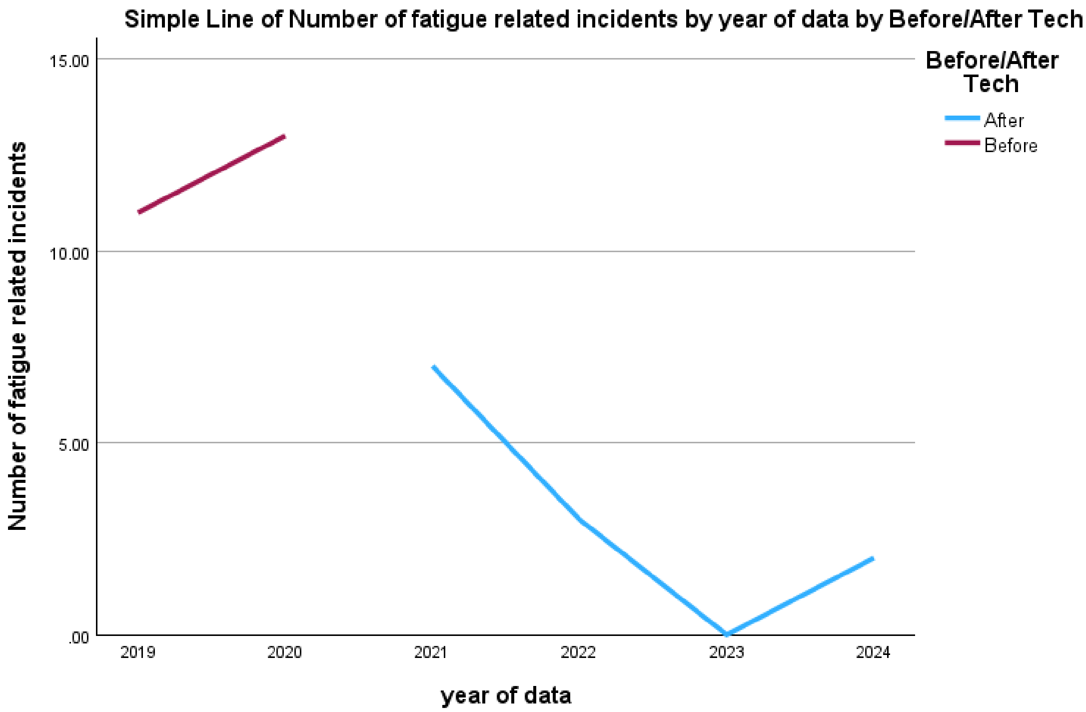
Descriptives

	Before/After Tech			Statistic	Std. Error
Number of fatigue related incidents	After	Mean		3.0000	1.47196
		95% Confidence Interval for Mean	Lower Bound	-1.6844	
			Upper Bound	7.6844	

		5% Trimmed Mean		2.9444	
		Median		2.5000	
		Variance		8.667	
		Std. Deviation		2.94392	
		Minimum		.00	
		Maximum		7.00	
		Range		7.00	
		Interquartile Range		5.50	
		Skewness		.941	1.014
		Kurtosis		1.500	2.619
	Before	Mean		12.0000	1.00000
		95% Confidence Interval for Mean	Lower Bound	-.7062	
			Upper Bound	24.7062	
		5% Trimmed Mean		.	
		Median		12.0000	
		Variance		2.000	
		Std. Deviation		1.41421	
		Minimum		11.00	
		Maximum		13.00	
		Range		2.00	
		Interquartile Range		.	
		Skewness		.	.
		Kurtosis		.	.

The Descriptive Statistics table shown above shows that the mean number of fatigue related incidents in the drilling department decreased from Mean = 12.000; Std = 1.41421 before technology was implemented (wearable detection sensors) to Mean = 3.0000; Std = 2.94392 after the implementation of technology in the processing department. This reduction in the number of fatigue related incidents clearly shows the effectiveness of wearable detection sensors in detecting unsafe situations surrounding workers.

<u>**Line Graph showing the number of fatigue related incidents over years**</u>



The graph shows a steady decrease in the number of fatigue related incidents in the years 2019 and 2020 before the implementation of automated drill rigs (marked by a pink line). The graph also shows a sharper decrease from the year automated drill rigs were first implemented that is 2021 to 2024 (marked by a blue line). This shows the new technology' effectiveness.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Fatigue Related Incidents (Before)	12.00	4	1.155	.577
	Fatigue Related Incidents (After)	3.00	4	2.944	1.472

The average number of fatigue related incidents went down from 12.00 before the use of wearable detection sensors to 3.00 indicating the improvement on safety after technology was implemented. A paired T- test revealed a p value = 0.009 showing that the reduction in incidents after the use of smart detection sensors for workers in the processing department is statistically significant since p= 0.009 < 0.05.

Paired Samples Effect Sizes

			Standardizer[a]	Point Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper
Pair 1	Fatigue Related Incidents (Before) - Fatigue Related Incidents (After)	Cohen's d	3.742	2.405	.328	4.454
		Hedges' correction	5.171	1.741	.237	3.223

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.
Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

The table shows the Cohen's d = 2.405 and this reflects the implementation of wearable detection sensors has had a strong impact since d>0.8. A Cohen's d measures the magnitude of change between two means therefore in paired samples, the mean difference shows the effect size between two related groups. The 95% confidence interval (0.328 to 4.454) shows that the true effect is considerable.

<u>LIKERT DATA</u>

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Wearable safety devices such as smart helmets and GPS trackers have improved worker safety	25	4.00	5.00	4.4800	.50990
Valid N (listwise)	25				

The above table shows the Likert Scale questionnaire response for the effectiveness of wearable safety devices in hazard detection. Generally responses showed strong agreement with a Mean =4.4800; Standard deviation=0.50990. The mean score of 4.4800 implies that respondents strongly leaned towards agreement with a strong consensus.

4.4.3.2 QUALITATIVE INSIGHTS

Interviewed contracted employees in the processing department highlighted improved safety standard through real time health monitoring, fatigue detection and fall detection as the main key themes. However, mine managers mentioned high initial cost of devices and maintenance as major challenges slowing down the full effectiveness of real time monitoring systems. One contractor went on to mention the durability of these devices under harsh conditions as another challenge.

4.5 CHALLENGES OF NEW TECHNOLOGIES

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation

Cost of implementing new technologies has been a major hindrance in the mining organization	25	4.00	5.00	4.7600	.43589
The use of new technologies is also being affected by inadequate and efficient staff training towards the use of these technologies	25	4.00	5.00	4.5600	.50662
Older employees are more resistant to adopting new technologies	25	2.00	5.00	3.5200	.91833
There is inadequate technical support and infrastructure to maintain new technology systems	25	2.00	5.00	4.4800	.91833
Incorporation of new technologies with existing systems is somewhat challenging	25	3.00	5.00	3.6000	.76376
Management commitment is a major hindrance to the implementation and success of these new technologies	25	3.00	5.00	4.2400	.72342
Resistance to change Is a major hindrance to technology Adoption	25	3.00	5.00	3.8000	.57735

Lack of adequate inclusion of new technologies in government legislations affects the success of new technologies	25	3.00	5.00	4.2400	.52281
Valid N (list wise)	25				

Table 4.4.1 shows the average responses for each of the 8 questions in relation to objective 2 (to assess the challenges associated with the adoption of new technologies in the mining sector). As shown in the table, the highest mean score (M=4.76) and a standard deviation (Std. Deviation = 0.43589) was for the item 'Cost of implementing new technologies has been a major hindrance in the mining organisation' indicating strong agreement among respondents. The lowest rated item 'Older employees are more resistant to adopting new technologies' with the lowest mean (M= 3.52) and a standard deviation (Std. Deviation = 0.91833) due to mixed perceptions across different groups. The column labelled N shows the number of people who answered the particular item and with 25 being recorded in all items indicates that all 25 of the respondents answered all questions fully. Generally, of the 8 items which assessed objective2, 5 of the questions had a mean (M) which was above (M=4) indicating strong agreement on the challenges associated with implementing new technologies to be cost of implementation; inadequate training; inadequate technical support; poor management commitment and inadequate inclusion in government legislations. The remaining 3 questions with means (M) ranging from M= 3.52 to M=3.80 indicate the different perceptions of some of the challenges across different groups.

4.5.2 RELIABILITY ANALYSIS

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.400	.354	8

Table 4.4.2 shows the reliability analysis for the items related to the effectiveness items stated in 4.4.1. The Cronbach's Alpha as shown in table was 0.400 which is below the normally accepted 0.70. This was due to the diverse perceptions among respondents arising mainly from variations in job role and their level of exposure to these technologies leading to inconsistent report patterns across the items.

4.5.3 ANOVA ANALYSIS

ANOVA

Challenges avg

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.533	3	.511	15.644	.001
Within Groups	.686	21	.033		
Total	2.219	24			

Table 4.5.2 shows the ANOVA (Analysis of Variance) results comparing items on objective 2 (challenges of implementing new technologies) perceptions by different groups (particularly by job role). This was done to determine whether job roles significantly influenced responses on objective1 (challenges of implementing new technologies). The table shows the variance in responses between groups as 1.533 (with a higher variation value) and the variance within groups as 0.686. The degrees of freedom (df=3) between groups represents the number of job roles (mine managers, contractors, engineers and safety officers) -1. The degrees of freedom within groups represents the number of respondents- the number of groups (25-4). As shown in the in

table 4.5.1 the sig. (p-value) is 0.001, therefore since $p<0.05$ the group differences are statistically significant. There was a statistically significant difference between at least one pair of job roles. This showed that job roles impact how respondents understand different challenges associated with implementing new technologies.

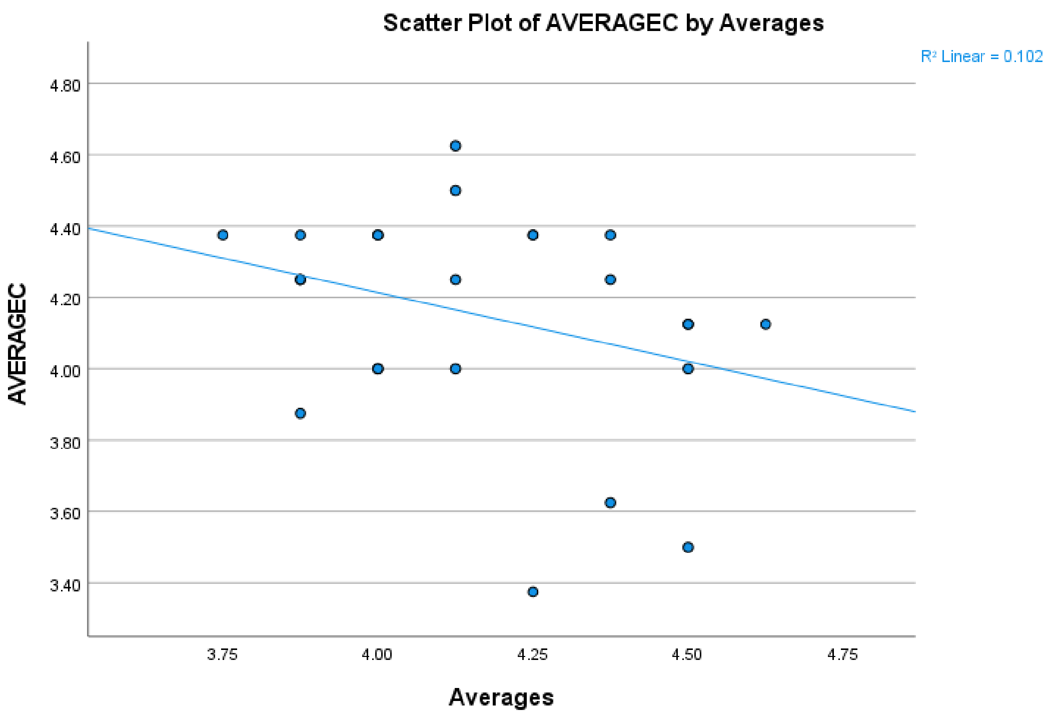
4.5.4 CORRELATION ANALYSIS

Correlations

		Effectiveness Averages	Challenges Averages
Effectiveness Averages	Pearson Correlation	1	-.320
	Sig. (2-tailed)		.001
	N	25	25
Challenges Averages	Pearson Correlation	-.320	1
	Sig. (2-tailed)	.001	
	N	25	25

Table 4.5 shows the correlation between the average scores of effectiveness (objective1) and challenges (objective 2). The Pearson Correlation shows the correlation coefficient which indicates the strength and direction of the relationship. The Sig. (2-tailed) value is the p-value used to determine statistical significance. The Sig. 2tailed value is 0.001as shown in the table. Since $p<0.05$ this means that the correlation is statistically significant. N shows the number of respondents used in the calculation which is 25. The Pearson correlation as shown in the table is -0.320 indicating a moderate negative relationship. This suggests that as the perceived effectiveness of new technologies increases, the perceived challenges of their implementation decreased therefore improving perceptions of technological usefulness may help alleviate the perceived challenges.

4.5.5 REGRESSION



The scatterplot on 4.7 displays the relationship between:

X -Axis (labelled as Averages) showing the Effectiveness of new technologies average score

Y -Axis (labelled as AVERAGEC) showing the Challenges of new technologies average score.

Each point on the scatterplot represents a respondent's average scores for both effectiveness items and challenges items. The line sloping down indicates the negative correlation, that is, as effectiveness increases, challenges decrease. R Square shows the variation in the dependent variable (challenges averages) which is explained by the independent variable/constant (effectiveness averages). R Square as shown in the table above is 0.102 meaning that 10% of the challenges variation is explained by effectiveness.

4.6 CONCLUSION

This chapter presented and analyzed the findings which are related to this study's objectives. SPSS was used to present and analyze the findings from historical mine data, Likert-Scale questionnaire and the responses from the interviews were grouped into common themes. The next chapter (Chapter 5) now brings out the discussion in accordance with the data presented in chapter 4.

CHAPTER 5: DISCUSSION

5.1 INTRODUCTION

The outcomes of the researcher's fieldwork were examined in the previous chapter, where they were displayed using tables, graphs, and statistical inference. This chapter further goes on to discuss the research findings and also backing up the discussion with previous literature studies.

5.2 INFLUENCE OF DEMOGRAPHICS ON STUDY FINDINGS

The demographic profiles of the respondents particularly job role and years of working experience revealed valuable insights on how certain background factors Influence perceptions on how new technologies improve mine safety. Respondents who had more than 10 years of working experience in the mining sector had a deeper appreciation and were more familiarized with new technologies and therefore gave deeper insights and responses. This aligns with the results of a study carried out by Jilke, S. (2021) on moderating the role of work experience on the Impact of technological uncertainty which highlighted that experienced workers have a deeper understanding and appreciation of technological innovations. Additionally, job roles also influenced perceptions and different view across the 4 examined job roles. This indicated variances in access or familiarity with specific technological innovations across different job descriptions. A study carried out by Mlekus, L., Lehmann, J., & Maier, G. W. (2022) on the Effects of task rotation in a technology-supported workplace suggested that task rotation in a planned manner improves technology familiarization, work motivation and therefore improving experience in a technology-facilitated workplace. This also brings out the importance of training across all departments.

5.3 EFFECTIVENESS OF NEW TECHNOLOGIES

Generally, Descriptive statistics Likert-Scale items pertaining to objective 1 (To assess the effectiveness of new technologies in hazard detection and risk mitigation) indicated that most respondents on the positive impact being brought about by new technologies in improving mine safety. This also shows that real time monitoring systems, autonomous machinery and systems are generally improving mine safety and contractor well-being. M.Long et al 2024' study on Equipment and Autonomous operations in the mining sector also stated the benefits of autonomous equipment such as Automated Haul Trucks and Automated Drill Rigs and also showed how this has been effective in separating humans from hazardous work conditions. Emerging technologies have significantly transformed many industries, and the mining industry is no exception, as it has also witnessed this transformation in various processes, from the exploration stage to the final processing of the ore (Bhattacharyya, S.S., and Shah, Y., 2022).

However, a study on the Barriers and Enablers of technology adoption in the mining sector carried out by A. Ediriweera., 2021 revealed that job roles influence technology adoption meaning that individuals with more skilled roles (engineers and mine mangers) are more likely to embrace new technologies. This had a great Influence on the perceptions of the full effectiveness of new technologies as viewed by different job roles and to support this, the Cronbach's Alpha was moderately a bit lower reflecting perception variation. This reflected how different job roles are not equally trained or familiarized to these new technologies.

5.4 CHALLENGES IN THEIR IMPLEMENTATION

Descriptive statistics on the Likert-Scale items pertaining to objective 2 (To assess the challenges associated with the adoption of new technologies in the mining sector) highlighted a number of challenges that are slowing down the effectiveness of technological innovations in the mining sector. Similarly, a study carried out by Sithole M.A (2024) on the drivers and barriers to digital Technology Adoption also brought out the key barriers to be financial constraints, lack of skilled personnel, inadequate training and regulatory uncertainties. These challenges were also echoed in the face-to-face interviews where participants with more years of working experience explained these challenges in detail also indicating that although technologies were effective, their progressive success is being hindered by these challenges. Sithole, M.A,.2024 suggested collaborative strategies such as public-private partnerships to reduce financial constraints and adequate training to all employees so as to alleviate the challenges.

5.5 DIVERSITY IN PERCEPTION ACROSS DIFFERENT JOB ROLES

The study revealed statistically significant differences in perceptions for both effectiveness and challenges particularly based on job role. Mine managers and engineers generally gave higher Likert-Scale scores on effectiveness items due to a greater exposure and familiarity with new technologies. Notably, contractors raised a great concern on limited training and limited access to technological equipment. A study carried out by P. Pacheco et al (2022) on the impact of empowerment and technology on safety behavior highlighted the need for empowering all employees in technology use as crucial for improving safety behaviors in the mining sector. A group-based variance by Adewale et al (2021) also observed that mine managers usually rate technological effectiveness more highly because of their active and direct participation in procurement and implementation. All these key findings bring out the importance of role-based training on technology use and familiarization so as to minimize these variances. This ensures that all job roles are well learned and informed on emerging technologies thereby improving mine safety and contractor well-being.

5.6THE RELATIONSHIP BETWEEN EFFECTIVENESS AND ASSOCIATED CHALLENGES

The Sig-2 tailed (p) value for the correlation between the perceived effectiveness of technologies and the perceived challenges was negative. As perceived effectiveness of technologies increases, the challenges of the technology's implementation decrease. This therefore highlights that addressing and reducing challenges increases the effectiveness of the technologies in improving mine safety and contractor well-being. Improving workers perceptions on technology usefulness through training will therefore lead to more familiarization and appreciation of new technologies. Ndlovu and Matanda (2021) also discussed the inverse relationship between technological effectiveness and perceived challenges also demonstrating how methods to increase technological reduce resistance and perceived difficulty. Technical challenges, financial constraints, inadequate training and poor management commitment negatively impacts the perceived effectiveness of safety technologies therefore ensuring adequate support is essential for successful implementation.

5.7 PREDICTORS OF PERCEIVED SAFETY IMPACT

A regression analysis was carried out to certain whether the perceived effectiveness of new technologies could significantly predict overall perceptions of safety improvement. A positive R-squared value as shown in chapter 4 a percentage of variance in perceived safety improvement can be explained by the effectiveness of technology. The negative beta value indicates that higher perceived challenges reduce the benefits about by these safety technologies. This is supported by the findings from Nyarko and Baafi (2020) who concluded that unresolved challenges lower the potential effectiveness of digital transformation in the mining sector. The regression analysis also shows that perceptions of technological effectiveness are key predictors of perceived benefits in safety and contractor well-being and also emphasizes the need to address challenges to maximize technological benefits.

5.8 Historical Trends in Mine Accidents

Analyses of historical mine accident data before and after technology implementation revealed a general decline in the number of accidents, near misses and LTIs. This decrease in the number of accidents, near misses aligns and agrees with the general effectiveness of new technologies in improving mine-safety. Similarly, a study carried out by L.J Zhou et al in 2019 revealed that the implementation of real time monitoring in Chinese Coal Mines contributed to improved safety performance and also lowered the risk of major accidents. Hague et al 2019 also carried out a similar study in South African gold mines noting down a 30% decline in the number of LTIs within a time frame of 3 years.

However, the graph also shows a non-uniform decline in the number of accidents whereby in some instances the graph reflects low increase in the number of accidents in some of the years. This pattern reflects the challenges associated with technology implementation. This is supported by Zhou et al.2020 who noted that although technologies generally Improved mime safety, its successful implementation is continuously hindered by a number of challenges. Therefore, addressing these challenges becomes imperative so as to ensure the success of new technologies in improving mine-safety.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

This study investigated the impacts of new technologies in hazard prevention and risk mitigation on mine safety and contractor well-being. For a well informed and knowledgeable insight, the study adopted a mixed methods approach integrating questionnaire data (for quantitative analysis) and interviews data (for qualitative analysis). This was also backed up by historical mine data on accident statistics before and after technology implementation.

Descriptive analysis on Likert-Scale items indicated the overall effectiveness of new technologies which is however, being affected by a number of challenges. This was backed up by the line graph showing a downward with few notable increases. ANOVA and Regression Analysis revealed notable group differences particularly by job role thereby suggesting that adoption and acceptance us not consistent across different job roles. Correlation and regression indicated a strong relationship between technology implementation and improved safety outcomes although this varies slightly across different technology types and operational areas.

While the results of this study are generally similar to other studies, the peculiarity of this study lies in its focus on Zimbabwean mining operations where technological effectiveness is hindered by financial constraints and infrastructure gaps unlike in other well-developed countries.

6 .2 LIMITATIONS

- Limited sample size to fully capture all subgroups in the mining industry
- Reliability of some Likert-Scale items due to differences in perceptions across different groups (job roles)
- Historical mine dataset only covered a limited period and might not therefore reflect long-term or future trends.

6.3 FUTURE RESEARCH NEEDS

- Need for comparative studies across multiple and different mining companies and also countries to assess extensibility
- Further research on the behavioral and psychological factors influencing technology adoption

6.4 RECOMMENDATIONS

Based on the research findings, the study recommends:

- Private-public sector partnerships to reduce financial constraints
- Investment in low cost and adjustable technologies that are practicable for resource constrained mining operations
- Aligning technology implementation with sustainability goals that are in accordance with Environmental, Social and Governance (ESG) commitments so as to promote long term viability
- Strengthening regulatory frameworks to mandate the use of safety technologies so as to create a baseline standard across the industry.

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APPENDICES

APPENDIX 1: CLOSE ENDED QUESTIONNAIRE

BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

DEPARTMENT OF ENVIRONMENTAL SCIENCE

Research Questionnaire

My name is LUCIA MUDARI, a student at Bindura University of Science Education, student number B212532B. I am conducting my final year research project on The Impact of new technologies on Hazard Prevention and risk mitigation and also the challenges associated with their adoption in the mining sector.

The purpose of this questionnaire is to solicit information and quantifiable data on the perceived effectiveness of these new technologies on hazard detection and risk mitigation and the challenges associated with their implementation in the mining sector. The information is to be gathered from different departments such as the mine managers, engineers, contractors, safety officers and other departments.

Responses to this questionnaire will be CONFIDENTIAL and in line with the research ethics hence they will not be given to anyone else without adequate permission.

Instructions

Respondents are advised to indicate their level of agreement by ticking in the appropriate box with their level of agreement. The responses are based on a 5-point Likert scale with the following statements

1. Strongly Disagree
2. Disagree
3. Neither Agree nor Disagree
4. Agree
5. Strongly Agree

For Section A (Demographic Information), Respondents are advised to tick in the appropriate box with the correct answer that matches them.

<u>SECTION A: Demographic information, work and perceptions or knowledge on new technologies in mine safety</u>

1. Gender

Male. ☐ Female. ☐

2. Job Role

Mine manager. ☐ Engineer. ☐ Contractor. ☐ Safety Officer. ☐

3. Level of Education.

Diploma. ☐ Degree. ☐ Masters. ☐ Other certificates☐

4. Years of Working Experience in the Mining Sector

<5years. ☐ 5-10years. ☐ 11-15years. ☐ >15years ☐

5. Age group (years)

18-30. ☐ 31-45. ☐ 46-60. ☐ Above 60. ☐

<u>SECTION B: Effectiveness of these new technologies in risk mitigation and hazard detection</u>

	<u>STRONGLY DISAGREE</u>	<u>DISAGREE</u>	<u>NEITHER AGREE NOR DISAGREE</u>	<u>AGREE</u>	<u>STRONGLY AGREE</u>
The use of real-time monitoring systems (gas sensors, surveillance cameras) has enhanced hazard detection in the mine.					
Wearable safety devices such as smart helmets and GPS trackers have improved worker safety.					
The use of drones has been effective in identifying hazardous zones before humans are exposed to them.					
Automated drill rigs have effectively reduced direct					

human exposure in hazardous or harmful working areas.					

SECTION C: Challenges associated with the implementation of new technologies in the mining sector

	STRONGLY DISAGREE	DISAGREE	NEITHER DISAGREE NOR AGREE	AGREE	STRONGLY AGREE
Cost of implementing new technologies has been a major hindrance in the mining organization.					
The use of new technologies is also being affected by inadequate and efficient staff training towards the use of these technologies					

Older employees are more resistant to adopting new technologies.					
There is inadequate technical support and infrastructure to maintain new technology systems.					
Incorporation of new technologies with existing systems is somewhat challenging.					
These new technologies are somewhat unreliable					
Management commitment is a major hindrance to the implementation and success of these new technologies.					
Resistance to					

change is a major hindrance to technology adoption.					
Lack of adequate inclusion of new technologies in government legislations significantly affects the implementation and success of new technologies					

APPENDIX 2: INTERVIEW QUESTIONS (Open ended questions)

Purpose: To explore broader insights, perceptions, and personal experiences related to the impact and challenges of new technologies in mining safety through the use of open-ended questions. Respondents will be asked to elaborate using examples and their personal experiences where applicable.

1. In your experience, how have new technologies affected safety in the mine?

2. What are the specific technologies that have greatly improved hazard detection and risk mitigation in the organization? Describe these technologies.

3. Has the organization experienced a significant reduction in accidents or incidents

since adopting new technologies? If yes, further elaborate on the specific improvements.

4. What technologies do you believe have made the most significant contribution to contractor wellbeing and how?

5. What are the major challenges being faced in the implementation or use of these new safety technologies?

6. What are your thoughts on the cost and sustainability of implementing such technologies across all mining operations?

7. Has the implementation of new safety technologies led to any form of resistance especially from older workers?

8. Is the Mine providing adequate training and capacity-building for staff regarding these technologies? Why or why not?

9. Briefly explain on how management support affects the success or failure of technology implementation and use?

10. What improvements would you suggest to make technology adoption more effective in enhancing safety and wellbeing?

APPENDIX 3: INSTITUTIONAL LETTER

DEPARTMENT OF ENVIRONMENTA SCIENCE

Bag 1020 BINDURA, Zimbabwe
Tel: 263 - 71 – 6505
Cell :0778371588
Email : vamugure@gmail.com

BINDURA UNIVERSITY OF SCIENCE EDUCATION

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05 December 2024

Dear Sir/Madam

REQUEST FOR PERMISSION TO COLLECT DATA FOR ACADEMIC RESEARCH PROJECT

PROJECT TITLE: ***EVALUATING THE IMPACT OF NEW TECHNOLOGIES ON HAZARD PREVENTION AND RISK MITIGATION AND THE CHALLENGES AFFECTING THEIR SUCCESSFUL IMPLEMENTATION TOWARDS IMPROVING MINE SAFETY AND CONTRACTOR WELL-BEING***

ACADEMIC SUPERVISORS: Mr P. Nhokovedzo

This letter serves to inform you that **LUCIA MUDARI, Registration Number (B212532B)** is a fourth year student at Bindura University of Science Education, in the Department of Environmental Science. During her fourth year of study she is supposed to do a research project in her area of specialisation.

Please assist in any possible way. Data collected will be used for academic purposes only and will not be published without your prior consent.

Thank you for your assistance.

Yours faithfully.

CHAIRPERSON
Department Of Environmental Science
Faculty Of Agriculture And Environmental Science
Bindura University Of Science Education
P. BAG 1020, BINDURA
ZIMBABWE
OFFICIAL

____
Mr T. Nyamugure
DEPARTMENT OF ENVIRONMENTA SCIENCE

APPENDIX 4: OTHER STATISTICAL TABLES

Statistics

		specify your gender	specify your job role	What is your highest level of education	years of work experience in the mining sector	Age group
N	Valid	25	25	25	25	25
	Missing	0	0	0	0	0
Mean		1.2800	2.6400	2.3200	2.1600	2.1600
Median		1.0000	3.0000	2.0000	2.0000	2.0000
Mode		1.00	3.00	2.00	2.00	2.00
Minimum		1.00	1.00	1.00	1.00	1.00
Maximum		2.00	4.00	4.00	4.00	4.00

Age group

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	18-30 years	7	28.0	28.0	28.0
	31-45 years	11	44.0	44.0	72.0
	46-60	3	12.0	12.0	84.0
	above 60 years	4	16.0	16.0	100.0
	Total	25	100.0	100.0	

What is your highest level of education

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	diploma	3	12.0	12.0	12.0
	degree	12	48.0	48.0	60.0
	masters	9	36.0	36.0	96.0
	other certificates	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Inter-Item Correlation Matrix

	Cost of implementing new technologies has been a major hindrance in the mining organization	The use of new technologies is also being affected by inadequate and efficient staff training towards the use of these technologies	Older employees are more resistant to adopting new technologies	There is inadequate technical support and infrastructure to maintain new technology systems	Incorporation of new technologies with existing systems is somewhat challenging
Cost of implementing new technologies has been a major hindrance in the mining organization	1.000	.445	-.092	-.012	-.050

The use of new technologies is also being affected by inadequate and efficient staff training towards the use of these technologies	.445	1.000	.333	.473	-.474
Older employees are more resistant to adopting new technologies	-.092	.333	1.000	.285	-.226
There is inadequate technical support and infrastructure to maintain new technology systems	-.012	.473	.285	1.000	.048
Incorporation of new technologies with existing systems is somewhat challenging	-.050	-.474	-.226	.048	1.000
Management commitment is a major hindrance to the implementation and success of these new technologies	.322	.528	.306	.572	-.121
Resistance to change Is a major hindrance to technology Adoption	-.033	-.313	-.189	-.126	.189
Lack of adequate inclusion of new technologies in government legislations affects the success of new technologies	-.468	-.214	.163	.097	.250

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
The use of real time monitoring systems (gas sensors, surveillance cameras) has enhanced hazard detection in the mine	Between Groups	.132	3	.044	.151	.928
	Within Groups	6.108	21	.291		
	Total	6.240	24			
The use of automation (autonomous machinery) has been effective in separating humans from unsafe working conditions	Between Groups	.308	3	.103	.456	.716
	Within Groups	4.732	21	.225		
	Total	5.040	24			
Wearable safety devices such as smart helmets and GPS trackers have improved worker safety	Between Groups	2.508	3	.836	4.705	.012
	Within Groups	3.732	21	.178		
	Total	6.240	24			
The introduction of AI and machine learning has been of great assistance in predicting and preventing potential mining accidents	Between Groups	15.945	3	5.315	19.195	.000
	Within Groups	5.815	21	.277		
	Total	21.760	24			
The use drones has been effective in identifying hazardous zones before humans are exposed to them	Between Groups	1.424	3	.475	2.179	.121
	Within Groups	4.576	21	.218		
	Total	6.000	24			

The use of data analytics and dashboards has enhanced decision making during emergencies in the mine	Between Groups	12.108	3	4.036	22.714	.000
	Within Groups	3.732	21	.178		
	Total	15.840	24			
Robotics have effectively reduced direct human exposure in hazardous or harmful working areas	Between Groups	1.015	3	.338	2.003	.144
	Within Groups	3.545	21	.169		
	Total	4.560	24			
Overall, new technologies have improved the safety culture at the mine	Between Groups	3.073	3	1.024	4.512	.014
	Within Groups	4.767	21	.227		
	Total	7.840	24			

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) specify your job role	(J) specify your job role	Mean Difference (I-J)	Std. Error	Sig.
The use of real time monitoring systems (gas sensors, surveillance cameras) has enhanced hazard detection in the mine	mine manager	engineer	-.23810	.37217	.918
		contractor	-.21212	.35128	.930
		safety officer	-.16667	.41191	.977
	engineer	mine manager	.23810	.37217	.918
		contractor	.02597	.26076	1.000
		safety officer	.07143	.33804	.997

	contractor	mine manager	.21212	.35128	.930
		engineer	-.02597	.26076	1.000
		safety officer	.04545	.31490	.999
	safety officer	mine manager	.16667	.41191	.977
		engineer	-.07143	.33804	.997
		contractor	-.04545	.31490	.999
The use of automation (autonomous machinery) has been effective in separating humans from unsafe working conditions	mine manager	engineer	-.04762	.32756	.999
		contractor	-.15152	.30917	.960
		safety officer	.16667	.36254	.967
	engineer	mine manager	.04762	.32756	.999
		contractor	-.10390	.22950	.968
		safety officer	.21429	.29752	.888
	contractor	mine manager	.15152	.30917	.960
		engineer	.10390	.22950	.968
		safety officer	.31818	.27715	.665
	safety officer	mine manager	-.16667	.36254	.967
		engineer	-.21429	.29752	.888
		contractor	-.31818	.27715	.665
Wearable safety devices such as smart helmets and GPS trackers have improved worker safety	mine manager	engineer	.04762	.29089	.998
		contractor	-.48485	.27456	.317
		safety officer	.33333	.32196	.731
	engineer	mine manager	-.04762	.29089	.998
		contractor	-.53247	.20381	.071
		safety officer	.28571	.26421	.704

	contractor	mine manager	.48485	.27456	.317
		engineer	.53247	.20381	.071
		safety officer	.81818*	.24613	.016
	safety officer	mine manager	-.33333	.32196	.731
		engineer	-.28571	.26421	.704
		contractor	-.81818*	.24613	.016
The introduction of AI and machine learning has been of great assistance in predicting and preventing potential mining accidents	mine manager	engineer	-.71429	.36312	.232
		contractor	1.18182*	.34274	.012
		safety officer	.25000	.40190	.924
	engineer	mine manager	.71429	.36312	.232
		contractor	1.89610*	.25442	.000
		safety officer	.96429*	.32982	.038
	contractor	mine manager	-1.18182*	.34274	.012
		engineer	-1.89610*	.25442	.000
		safety officer	-.93182*	.30724	.030
	safety officer	mine manager	-.25000	.40190	.924
		engineer	-.96429*	.32982	.038
		contractor	.93182*	.30724	.030
The use drones has been effective in identifying hazardous zones before humans are exposed to them	mine manager	engineer	.66667	.32212	.196
		contractor	.57576	.30404	.261
		safety officer	.16667	.35652	.965
	engineer	mine manager	-.66667	.32212	.196
		contractor	-.09091	.22569	.977
		safety officer	-.50000	.29258	.344

	contractor	mine manager	-.57576	.30404	.261
		engineer	.09091	.22569	.977
		safety officer	-.40909	.27255	.455
	safety officer	mine manager	-.16667	.35652	.965
		engineer	.50000	.29258	.344
		contractor	.40909	.27255	.455
The use of data analytics and dashboards has enhanced decision making during emergencies in the mine	mine manager	engineer	-.04762	.29089	.998
		contractor	1.48485*	.27456	.000
		safety officer	.66667	.32196	.195
	engineer	mine manager	.04762	.29089	.998
		contractor	1.53247*	.20381	.000
		safety officer	.71429	.26421	.059
	contractor	mine manager	-1.48485*	.27456	.000
		engineer	-1.53247*	.20381	.000
		safety officer	-.81818*	.24613	.016
	safety officer	mine manager	-.66667	.32196	.195
		engineer	-.71429	.26421	.059
		contractor	.81818*	.24613	.016
Robotics have effectively reduced direct human exposure in hazardous or harmful working areas	mine manager	engineer	.00000	.28354	1.000
		contractor	.36364	.26763	.538
		safety officer	.50000	.31382	.404
	engineer	mine manager	.00000	.28354	1.000
		contractor	.36364	.19866	.288
		safety officer	.50000	.25754	.242

	contractor	mine manager	-.36364	.26763	.538
		engineer	-.36364	.19866	.288
		safety officer	.13636	.23991	.940
	safety officer	mine manager	-.50000	.31382	.404
		engineer	-.50000	.25754	.242
		contractor	-.13636	.23991	.940
Overall, new technologies have improved the safety culture at the mine	mine manager	engineer	-.23810	.32879	.886
		contractor	.51515	.31034	.369
		safety officer	.58333	.36390	.398
	engineer	mine manager	.23810	.32879	.886
		contractor	.75325*	.23037	.018
		safety officer	.82143	.29864	.054
	contractor	mine manager	-.51515	.31034	.369
		engineer	-.75325*	.23037	.018
		safety officer	.06818	.27819	.995
	safety officer	mine manager	-.58333	.36390	.398
		engineer	-.82143	.29864	.054
		contractor	-.06818	.27819	.995

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons

Dependent Variable: Cost of implementing new technologies has been a major hindrance in the minir organization

Tukey HSD

(I) specify your job role	(J) specify your job role	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bou
mine manager	engineer	.09524	.27689	.986	-.6765	.8670
	contractor	-.33333	.26135	.588	-1.0618	.3951
	safety officer	.16667	.30646	.947	-.6875	1.0209
engineer	mine manager	-.09524	.27689	.986	-.8670	.6765
	contractor	-.42857	.19400	.153	-.9693	.1122
	safety officer	.07143	.25149	.992	-.6296	.7724
contractor	mine manager	.33333	.26135	.588	-.3951	1.0618
	engineer	.42857	.19400	.153	-.1122	.9693
	safety officer	.50000	.23428	.175	-.1530	1.1530
safety officer	mine manager	-.16667	.30646	.947	-1.0209	.6875
	engineer	-.07143	.25149	.992	-.7724	.6296
	contractor	-.50000	.23428	.175	-1.1530	.1530