Overcoming barriers to the adoption of technology in the mining industry to enhance safety and productivity: A scoping review

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Abstract. This study examines the adoption of technology in the African mining sector, with a focus on digital integration to enhance sustainability, safety, and efficiency. It examines developments in Mining 4.0 around the world and points out obstacles specific to Southern Africa. PRISMA was used to do a systematic literature review (2020–2025) across five databases. The lack of an integrated framework that combines the Tech-Technology Organisation Environment (TOE), Diffusion Of Innovation (DOI), and Unified Theory of Acceptance and Use of Technology (UTAUT) models, and the scant attention paid to user interfaces and human-centric design (HCD), and the lack of contextual specificity In the research that has already been done, there are significant gaps. The goal of the study is to develop a comprehensive, inclusive framework suited to the area's diverse workforce and socio-technical realities.

1. Introduction

The African mining industry, a cornerstone of the continental economy, faces increasing
pressure to enhance operational efficiency, safety and sustainability [1]. The global push toward "Mining 4.0" necessitates the adoption of advanced technologies such as automation, IoT, data analytics, and augmented reality (AR) [2]. These technologies improve resource management, reduce downtime, and increase operational efficiency [3]. Early hazard detection using real-time monitoring increases safety [4]. Improved waste management and energy efficiency reduce environmental impact. In general, digital integration in contemporary mining promotes sustainability and production [5].

Numerous countries have adopted Industry 4.0 and are witnessing impressive mining outcomes [6]. With hundreds of autonomous drills and sophisticated data systems that increase productivity and sustainability, North America, especially the US and Canada, is at the forefront of the adoption of smart mining [7]. Australia has established cloud-based control rooms and semi-autonomous operations throughout its extensive mining terrain, making it a global leader in digital mining [7]. However, the successful Implementation of these technologies in Southern Africa is not guaranteed and is often impeded by complex social, organisational, and human factors [8]. The existing literature presents various models to explain technology adoption [4]. There is a significant research gap in integrating these theoretical frameworks with the practical principles of human-centric design, specifically tailored to the unique socioeconomic context and diverse workforce of the Southern African mining sector. The successful implementation of new technologies for operational excellence in the

The Southern African mining industry is being compromised by a high rate of technology rejection or underutilization. This problem stems from a failure to address the multifaceted nature of adoption, which requires a holistic approach that simultaneously considers organisational-level drivers, social diffusion patterns, and individual user acceptance. The absence of a dedicated framework that integrates established theoretical models with human-centric design principles, tailored for the local context, leads to inefficient technology rollouts and a suboptimal return on investment. The question of research is, to what extent May mining operations in Southern Africa benefit from an integrated, human-centric framework that promotes the adoption of improved technology? This proposal outlines a study to bridge this gap by developing and validating a comprehensive framework for technology adoption. The goal of this study is to provide a thorough overview of current practices and trends by systematically identifying and mapping the range of data on technology adoption in the African mining industry. It also aims to categorise and explain the main political, social, and infrastructure obstacles that prevent technical advancements from being successfully incorporated into the industry.

The goal of the study is to identify and summarise the methods and enabling elements that have been proposed to overcome these obstacles. These are examined in the body of existing literature. To promote more equitable and sustainable technological

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improvement in African mining, it concludes by highlighting important research gaps and making recommendations for future studies and policy creation.

This research will make a dual contribution to both academic theory and practical application. The primary academic contribution will be the development of a novel, integrated framework for technology adoption that synthesises established theoretical models with the principles of human-centric design. This framework will bridge a critical gap in the
literature and provide a new lens for future research in similar industrial contexts. The research will provide a practical, evidence-based tool for industry leaders, technology Developers and policymakers in Africa. The findings will offer actionable insights into the key drivers and barriers of technology adoption, enabling the development of more effective and targeted implementation strategies. This will ultimately lead to improved operational efficiency, enhanced safety and a more sustainable future for the African mining sector.

2. Materials and Methods

This literature review investigates mining technologies, adoption frameworks, and man-centred approaches, emphasising their relevance to the Southern African mining landscape. It highlights significant gaps in behavioural integration and contextual adaptation that impede successful technology implementation. Through an analysis of mining techniques, industry-specific challenges, and transition opportunities, the review establishes a foundation for a more inclusive and sustainable strategy for technology adoption, one that harmonises innovation with workforce requirements and operational conditions.

A comprehensive systematic literature review was carried out using the PRISMA methodology. The study took place in August 2025 and utilised five databases: ScienceDirect, OneMine, Scopus, PubMed, and Web of Science. Only studies published between 2020 and 2025 were considered. The search employed the phrase “adoption of technology in mining,” with keywords including “Technology,” “mining,” and “adoption.” Key filtering criteria included journal articles in English related to Engineering and Computer Science, available fully online, and tagged with mining, automation, and adoption as subject terms. Selected article types focused on Engineering, Computer Science, the Computer Industry, and AI applications. The initial search yielded 3,771 journal articles along with three additional sources not found online. After removing duplicates, 1,500 documents remained. These were filtered by title, reducing the count to 750. Further filtering by abstract narrowed the selection to 250 documents. From these, full-text articles were reviewed for eligibility, resulting in 14 journals that were ultimately included in the study, as illustrated in Fig. 1.

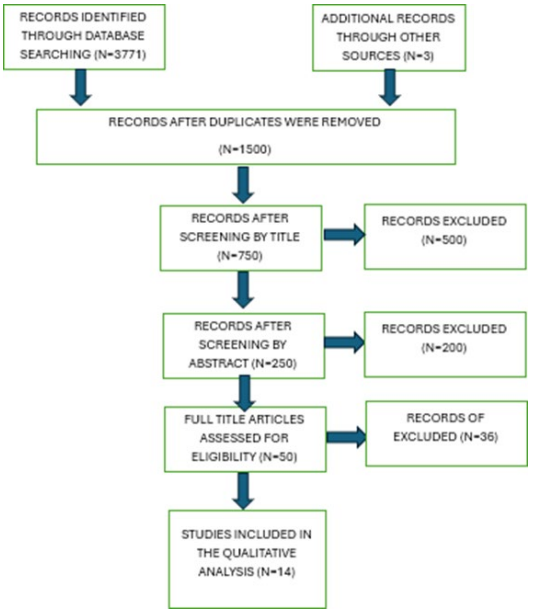

Fig 1. PRISMA diagram

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) diagram describes the process of study selection. The preferred Reporting Items for Systematic Reviews and Meta-Analysis diagram describes the process of the study selection.

3. Results

Table 1 is a product of the included journals that the research considered for qualitative research.
Analysis. An analysis of 14 studies on the adoption of technology in the mining sector
shows a range of research from different nations, emphasising the advantages such as increased
production, security, and decision-making. Although technologies like artificial intelligence-
AI, hyperspectral imaging, and data integration platforms have shown promise,
They also have drawbacks and areas for further study, such as costs and restrictions at the
individual level. These technologies have the potential to revolutionise the sector, but further study is required to fully understand their advantages and create practical implementation plans.

Table 1. Literature review table

Summary of Mining Technology Studies

Author	Country	Type of Mine	Methods Used	Results	Limitations / Future Work
Tariq et al. (2025)	Sweden	Iron ore mine	Qualitative	Limited data was used.	
Cacciuttol et al. (2023)	China	All mines	Systematic review, PRISMA diagram, mixed methods	Offers new levels of security, stability, and predictability ; reduced uncertainties in mining.	
Alkhenin (2024)	Canada	Open-pit mine	Data management analysis for predictive maintenance	Power BI enables detailed maintenance analysis and informed decision-making.	
Elisabeth and Aarti (2020)	Germany	All mines	Systematic and comprehensive review	Mining requires technological and societal shifts to improve industry image.	
Berci et al. (2020)	South Africa	Underground mines	Multi-criteria decision making, fusion analytics, analytic hierarchy process	AI emerged as the top technology choice.	Relied on limited external data; future research on long-term benefits needed.
Author	Country	Type of Mine	Methods Used	Key Findings	Challenges / Future Research
Ediriweera and Wiewiora (2010)	Austria	All mines	Qualitative analysis	Examined organisational and environmental factors influencing innovation adoption in mining.	
Nasirov et al. (2018)	Chile	All mines	Qualitative approach, survey, semi-structured workshops, data analytics	Identified fear of technology replacement; highlighted need for user-focused systems.	Data privacy constraints due to consent limits.
Marko et al. (2024)	Glasgow	All mines	Quantitative	Measured signal loss of 10–15 dB at loader top scoop position (FR1).	Limited mine access; future work should optimise underground communication.
Seppo et al. (2024)	Spain	All mines	Proof-of-concept implementation	Demonstrated feasibility of hyperspectral mapping in challenging underground mines.	Future research should assess full-scale implementation.
Jingfeng et al. (2024)	China	Coal mines	Comprehensive approach, data standards	Developed a successful mine-side data platform improving data quality.	Future research should explore real-time implementation.

Based on a review of the existing body of knowledge, the following gaps in the literature have been identified: Lack of an Integrated Framework: Current research predominantly applies adoption models in isolation. There is a lack of a single, comprehensive framework that synthesises the macro-level insights of TOE, the social diffusion dynamics of DOI, and the micro-level behavioural predictions of UTAUT [10]. Insufficient Focus on Human-Centric Design (HCD): The role of HMI/UX in facilitating or hindering technology adoption in the African mining context remains underexplored [11]. There is a need for research investigating how user-friendly designs, including haptics, augmented reality, and simplified visual dashboards, directly influence adoption rates among a workforce with varying levels of digital literacy [13]. Contextual Specificity: Most technology adoption studies are based on data from developed nations. There is a critical need for empirical research specific to the African mining industry, considering its distinct socio-technical characteristics, legacy infrastructure, and unique workforce demographics [12]

4. Discussions

4.1 Strategies and enablers of technology adoption in mining

To support technology adoption in the African mining industry, a range of strategies and enablers have been identified across technological, human, policy, and economic dimensions [13]. Technological solutions focus on deploying robust, simplified systems and developing fit-for-purpose innovations suited to mining environments [14]. Human-centric approaches emphasise targeted training, skills development, stakeholder engagement, and fostering a culture of innovation to ensure workforce readiness [15]. Policy and governance strategies involve creating stable regulatory environments, offering government incentives, and encouraging public-private partnerships to build a supportive ecosystem [14]. Economic solutions aim to lower financial barriers through innovative financing models, technology leasing, and collaborative cost-sharing among mining companies [16]. Collectively, these strategies provide a comprehensive and practical foundation for promoting sustainable, inclusive, and context-sensitive technology adoption across the African mining sector.

4.2 Impact on safety and productivity

Technology can greatly improve mining safety and production, according to the results
of the studied literature. Innovations like remote operations, real-time monitoring, and
autonomous equipment are significantly responsible for safety advances since they limit

Human exposure to dangerous settings facilitates early risk detection [17]. Enhanced operating procedures, predictive maintenance systems, and less equipment downtime are all associated with increased productivity, which in turn leads to more effective use of 3 resources and streamlined tasks. However, the literature also
emphasises the difficulties in quantifying these impacts because of the scarcity of empirical data, the

unpredictability of measurements, and the intricate interactions between environmental, human, social and technical factors that affect results.

4.3 Strengths and Limitations of the Review

The analysis found that high capital costs, a lack of funding, inadequate infrastructure, a lack of skills, opposition to change, and policy uncertainty are the main obstacles to the adoption of technology in African mining. Strong technologies, focused training, stakeholder involvement, stable governance, incentives, and cooperative funding are examples of enablers. Governments, technological corporations, and mining businesses use these insights to guide their decisions. Clearer rules and investment incentives to encourage Innovation are among the policy ideas. The review's thorough and methodical approach, mapping the literature on a pertinent issue, is its strongest point. However, relying just on published sources could leave out important grey literature, and it can be difficult to synthesise different study methods and results. Future studies that address these constraints will improve knowledge and aid in the creation of inclusive, situation-specific frameworks for the mining industry in Africa to adopt sustainable technologies.

5 Conclusion

A comprehensive strategy involving multiple stakeholders is needed to overcome the obstacles to technology adoption in African mining. In addition to financial investment, resolving fundamental challenges like infrastructure development, human capacity building, and establishing stable political and regulatory environments are essential for a successful shift to a more technologically advanced mining sector. By putting these tactics
In practice, African mining firms may use technology to greatly improve production
and safety, guaranteeing a more competitive and sustainable future for the sector.

Abbreviations

TOE Technology Organisation Environment

UATUT Unified theory of Acceptance and Use of Technology DOI Diffusion of Innovation

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