Barriers and Enablers of Technological Adoption in Zimbabwe's Underground Chrome Mining: Implications for Strategic Decision-Making

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ABSTRACT
The research investigates barriers and enablers that affect technological adoption within Zimbabwe's underground chrome mining operations aiming to improve strategic decision making for industry stakeholder. The sector faces major obstacles to technological advancement because it lacks proper infrastructure and faces regulatory hurdles and insufficient financial resources. The sector can enhance technological integration through skilled labor together with government support and industry collaboration. The research combines mixed methods to analyze the perspectives of miners alongside government officials and technology providers. The research shows that barriers and enablers form a complex relationship which needs tailored solutions to address specific challenges by leveraging existing advantages. The research provides actionable recommendations to policymakers and industry leaders who aim to establish better conditions for technological advancement which can drive sustainable growth in Zimbabwe's chrome mining sector.

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Introduction

Underground chrome operations in Zimbabwe's mining industry identify technology adoption as their essential factor for enhancing operational efficiency alongside safety measures. The rising international market competition requires mining companies to implement modern technologies for their survival and operational productivity. Advanced technologies represent an essential requirement for sustainable economic development of the mining sector in Zimbabwe. This journal entry investigates my research about technological adoption barriers and enablers that influence strategic choices in underground chrome mining operations.

The mining industry of Zimbabwe faces various obstacles during technology implementation despite its potential advantages. Modern technology implementation faces challenges because of economic instability together with inadequate infrastructure and regulatory obstacles. Workers who maintain traditional practices demonstrate strong resistance to cultural change which creates a major obstacle for innovation. These identified challenges enable stakeholders to understand the complex process of technological adoption. Mining companies must identify obstacles that prevent their progress so they can develop specific plans to overcome these challenges while establishing an innovative work environment.

Multiple factors exist which support the implementation of technology within the mining industry. The successful integration of technology depends on strong management, backing together with beneficial government policies and extensive training initiatives. Organizations can enhance their operational performance and decision-making abilities through these enablers. The research examines how knowledge about barriers and enablers relationships helps organizations make strategic decisions to enhance mining efficiency and safety in Zimbabwe.

Literature Review

The adoption of technology in mining operations has become a major research focus because of its critical role in underground chrome mining in Zimbabwe. The mining industry requires technological advancements to address its critical issues of resource depletion and market instability and environmental preservation challenges. The review evaluates

existing studies about mining technology adoption barriers and enablers with specific attention to Zimbabwe's unique socio-economic and regulatory environment. Research studies have identified multiple factors which affect technology adoption including organizational culture and workforce skills together with infrastructural limitations and governmental policies. This review analyzes these dimensions to develop a comprehensive understanding of technological integration within Zimbabwe's chrome mining industry. The research findings will direct strategic decisions while offering vital information to policymakers and industry stakeholders and researchers. The literature review aims to improve sustainable mining discussions while directing future research in this field.

Technology

The application of scientific knowledge along with innovative tools according to Sánchez, et al (2023) enhances operational efficiency and safety and productivity within underground mining. Mining enterprises benefit from technological progress because it helps them understand resource combinations better while creating improved capital goods. Technology plays a vital role in the mining industry because it functions as both a force for social transformation and a tool for resolving existing problems such as safety issues and environmental consequences (RM Izatt et al., 2014). The mining industry applies technology for planning functions which managerial staff members execute (Davis, G. A., & Newman, A. M,. 2008). Aznar-Sánchez et al. (2019) defined innovation as any activity ranging from mechanization to automation that transforms mining operations to improve safety measures and communication and environmental practices. The technological advancements serve two purposes by optimizing operational efficiency and reshaping mining operations through their influence on social and economic structures which enhances decision-making capabilities.

Internet of Things (IoT)

The system of connected devices and objects which interact and share data through the internet was described by Gokhale et al in 2018. The Internet of Things (IoT) includes all types of equipment which range from home appliances to industrial machines that send data through sensors and software and multiple technologies. The Internet of Things (IoT) transforms underground mining operations through its capability to link devices and systems across internet networks according to Aziz (2020). The Internet of Things (IoT) functions through sensors and devices and software that exchange real-time data throughout its network. The implementation of IoT technology in underground mining operations allows real-time monitoring of environmental conditions as well as equipment performance and worker safety according to Chilunjika (2024). Underground mining operation sensors track environmental metrics such as air quality and temperature and humidity levels to generate vital data for workplace safety maintenance. Through equipment health monitoring IoT devices execute predictive maintenance which results in both reduced equipment downtime and lower maintenance expenses. Real-time data collected from IoT systems enhances underground mining decision-making because it enables proactive responses to potential issues. Underground mining IoT system deployment provides real-time monitoring yet Berin (2017) states that security risks and cyber-attacks together with limited infrastructure development present major hurdles for developing countries.

Artificial Intelligence (AI)

Zeba et al,. (2021) defined AI as the process of simulating human intelligence through machines that duplicate human thinking and learning capabilities. The systems perform cognitive tasks which include reasoning and problem-solving along with natural language understanding and pattern recognition. Underground mining operations now heavily rely on Artificial Intelligence (AI) and data analytics as fundamental components of their operations. Pattern recognition for predictive purposes emerges from AI algorithms which process data gathered from geological surveys as well as equipment sensors and operational metrics (Singh G et al., 2024). Resource extraction strategies can be optimized through this capability which leads to improved ore quality and enhanced operational efficiency for mining companies. The predictive capabilities of AI models enable the forecasting of equipment breakdowns before they happen which leads to early decision-making opportunities.

The following benefits or main areas for AI implementation in underground mining appear according to AI world school (2020).

Fig 1 Benefits of AI 1Source: AI world school (2020)

The mining sector

Underground chrome mining operations in Zimbabwe undergoes substantial changes due to technological advancements according to Dube et al. (2016). The industry operated with manual workers and traditional practices until it adopted modern technological solutions to improve its decision-making capabilities. The industry transformation leads to better operational efficiency and productivity while addressing fundamental safety risks which exist in underground mining operations. The sector needs to deploy advanced communication networks with digital tools including Internet of Things (IoT) and artificial intelligence according to Arsenio et al (2013). Technology enable real-time data transfer and remote observation functions which allow operators to make decisions based on exact information to achieve better safety results and maximize resource usage. The literature review analysis examines technological effects on Zimbabwean underground chrome mine decision-making while discussing their impact on safety standards and industrial productivity and expansion. Underground mining operations experienced major changes in their decision-making systems because of technological development. According to M Onifade et al 2023 technology implementation leads to improved safety conditions and increased efficiency and sustainability in underground mining operations. Further research, including literature review, is needed to understand the influence of technology on decision-making processes in underground mining operations. The review examines academic research about technological influences on safety standards together with productivity levels and cost management in underground mining decision-making processes. The review performs literature analysis to determine the effects of technological solutions on underground mining operations.

Decision-making

According to Uzonwanne (2016) every human being performs decision making throughout their day. People start making decisions from their first awakening when they open their eyes in the morning between choosing to hit the snooze button or getting out of bed. Decisions keep being made throughout the day until the body makes the decision to shut its eyes for sleep. George R. Terry (2013) defines decision-making as the process of choosing the best option from multiple alternatives based on specified criteria. The process of decision-making involves identifying suitable alternatives for specific circumstances through measures.

Decision-making in underground mining

The process of underground mining decision-making according to S Pimentel et al., (2016) consists of selecting the optimal course of action from available alternatives to achieve maximum efficiency and safety and productivity. Several studies have proven that technology plays a significant role in this process. Berry et al,. (2009) demonstrated that data mining techniques extract valuable information from complex datasets which support strategic decision-making. Vongpaisal et al. (2011) presented an expert system module for underground mining decision-making which demonstrates how advanced technologies enhance operational choice capabilities. Dayang et al. (2017) demonstrated that grout injection technology stabilizes excavations which impact safety-related choices. Balusa et al. (2018) explained multiple criteria decision-making models that demonstrate the difficulty in selecting appropriate mining methods. The studies reveal how technology continues to reshape decision-making approaches which lead to better operational safety and efficiency in underground mining operations.

Instances of Technology Adoption Failure in Zimbabwe

Failure Instance one

Masere studied technology adoption challenges in Zimbabwean small-scale mining operations in his 2018 research about Zimbabwean mining sector technology barriers. Advanced mining equipment requires high initial investments which prevent the Zimbabwean mining sector from adopting new technologies at scale. The initial expenses of modern drilling rigs and processing facilities act as a barrier for these miners to enhance operational safety and efficiency. Masere states that small-scale miners in the Midlands province struggle to shift from conventional techniques to contemporary flotation processing systems during his research. Masere states that operational expenses and technological instruction costs prevent miners from adopting modern technologies since their financial resources are limited. The analysis indicates that Zimbabwean mining operations require both financial backing and implementation frameworks to successfully integrate modern technology and boost their mining sector performance.

Failure Instance two

The research by Mlambo in 2017 reveals that inconsistent power supply systems operate as main challenges to integrate modern technology across Zimbabwean mining sites. According to Mlambo power outages create operational disruptions that stop mining operations from adopting complex machinery that needs stable electricity to function. Automated ore sorting and real-time monitoring technologies remain non-operational at the Great Dyke region mines because of persistent power instability. Mining operations face market competition challenges because alternative power sources increase operational expenses which prevent technology system upgrades. Research shows that Zimbabwean energy infrastructure needs immediate improvement to help the mining sector reach technological advancement goals.

Failure Instance three

P. M. Chikanda's 2021 study "Educational Barriers to Technology Adoption in Zimbabwe's Mining Sector" functions as an essential source. Chikanda's research shows that insufficient training of miners hinders their ability to implement advanced technology solutions containing artificial intelligence (AI). Chikanda shows that basic digital competencies and technical abilities are absent among many small-scale miners which hinders their ability to use modern mining equipment and software. According to Chikanda, the Midlands mining operations have expressed interest in AI technology, yet their insufficient understanding of these systems makes it unusable. The Zimbabwean mining sector faces reduced competitiveness and productivity because educational programs and training remain absent which prevents miners from accessing AI and other technological benefits.

Instances of Technology Adoption successes in Zimbabwe

Success instance one

T. Nyoni presents a significant case study in his paper "The Impact of Artificial Intelligence on Productivity in Zimbabwe's Underground Mining Sector" (2022). Nyoni examines the successful implementation of AI technology in underground mines across Zimbabwe through automated drilling and predictive maintenance system implementation. According to this research, AI technologies deliver major advantages for operational efficiency and safety performance. The implementation of AI systems at Shabanie Mine optimizes drilling patterns and leads to a 30% boost in ore recovery rates according to Nyoni. The implementation of predictive maintenance technology has reduced equipment downtime by 25% which produces major cost savings according to Nyoni. The research outcomes of Nyoni show that AI adoption enhances both operational productivity and safety measures which positions Zimbabwean underground mining to become more competitive globally.

Success instance two

C. M. Dube presents relevant information in the paper "Harnessing Technology: The Role of AI in Enhancing Underground Mining Operations in Zimbabwe" (2023). Dube analyzes the successful implementation of artificial intelligence (AI) technologies at the Mimosa Mine which operates underground mining in Zimbabwe. The mine deployed AI systems for data analytics and predictive maintenance to boost operational performance significantly.

The Mimosa Mine obtained its success by investing in training programs that made both employees and workers proficient in handling new technologies effectively. The company delivered educational programs about mining-specific data interpretation alongside machine learning techniques for employees. The mine worked with technology providers to create customized AI solutions which matched their operational requirements for ventilation system optimization and sorting process enhancement.

The implemented initiatives led Mimosa Mine to achieve both a 20% improvement in production efficiency and lower operational expenses. The research by Dube demonstrates that underground mining success through AI adoption requires trained personnel alongside strategic technology partnerships and customized solutions which can drive Zimbabwe's mining sector growth.

Knowledge Gap

The field of underground chrome mining technology has gained more attention for efficiency and safety improvements, yet researchers still need to address the barriers and enablers that affect technological adoption in Zimbabwe. The special combination of social economic and political elements in the country creates obstacles which current research fails to resolve. The successful implementation of technology in this sector requires knowledge about local dynamics including regulatory frameworks economic conditions and cultural attitudes toward technology.

Research about the views of stakeholders who work in mining operations including miners and management, and local communities remains scarce. Research on stakeholder concerns and change resistance and motivations helps identify the specific barriers to technology adoption. The successful deployment of new technologies remains unclear because of insufficient research about the effects of infrastructure elements including power supply and internet connectivity. The success of technological advancements in underground mining operations depends on addressing these factors because they directly impact feasibility and effectiveness.

The investigation of training and skills development initiatives as drivers of technology adoption requires additional research. The understanding of workforce readiness as a factor for new technology integration enables organizations to develop strategic plans and allocate human capital resources effectively. The economic feasibility of technological advancements in Zimbabwean underground chrome mining lacks sufficient cost-benefit analysis in existing research. The identification of knowledge gaps enables stakeholders to create targeted strategies that account for local conditions and stakeholder needs which leads to better technology integration in the sector.

Theoretical framework

The framework provides a systematic approach to study how technological progress impacts operational performance alongside security measures and productivity. The Unified Theory of Acceptance and Use of Technology (UTAUT) which Venkatesh et al. introduced in 2003 serves as a complete framework to study user intentions toward technology adoption and their subsequent usage patterns. The UTAUT model unites essential elements from previous models through its performance expectancy and effort expectancy and social influence and facilitating conditions constructs. The UTAUT model helps Zimbabwe's underground chrome mining sector identify which factors influence miners and management when deciding to adopt new technologies. The innovation's perceived impact on productivity and safety levels corresponds to performance expectancy while effort expectancy focuses on user technology ease of use. Social influence examines how peers along with organizational culture affect acceptance while facilitating conditions assess the required resources and support needed for successful implementation. The research uses UTAUT to analyze technology adoption barriers and enablers in a systematic way which produces findings that help develop strategic decisions and improve innovative solution integration in mining operations.

Methodology

The research design used a qualitative approach which involves qualitative interviews to achieve research objectives. The research design enabled a thorough investigation of the obstacles and facilitators that affect technology adoption. The selection of participants proved essential because it involved working with mine managers alongside safety officers and operational staff. The development of professional relationships with participants became vital for obtaining their valuable insights about their technology experiences and perceptions. The data collection process included distribution of semi-structured interviews (Sikalumbi, 2023). The semi-structured interviews allowed participants to share detailed information about their technology adoption challenges and successes. This research method produced more detailed findings which helped explain the intricate process of integrating technology into underground mining operations.

Underlying Philosophy

The research bases its approach on interpretivist to study the intricate social realities and personal experiences of stakeholders operating in Zimbabwe's underground chrome mining sector. The research used qualitative methods including in-depth interviews to understand the detailed perspectives and personal meanings that people assign to their technological adoption experiences. The research method acknowledges that each participant's perspective emerges from their individual circumstances, which produces more detailed knowledge about technology adoption barriers and enablers. The interpretivist approach enables strategic decision-making through insights that stem from the actual experiences of mining industry participants.

Sampling frame and size

The research investigates s and facilitators of technological adoption in Zimbabwean underground chrome mining through purposive sampling. The sampling method allows researchers to choose participants who have direct knowledge about the research subject. The sampling consists of mining company management and operational staff together with mining technology experts and government officials from regulatory bodies and local industry association representatives and community leaders who experience mining impacts. The study targets these groups to obtain detailed information about mining sector technology adoption complexities while ensuring the collected perspectives remain both knowledgeable and applicable.

The research used a purposive sample of 12 participants because qualitative research requires this number for in-depth interviews. The study sample consists of four equal parts between supervisors and policy officials and technology vendors and ventilation specialists. Supervisors maintain essential roles in mining operations because they lead both the workforce and all operational processes. The practical difficulties of implementing new technologies beneath the earth's surface are best understood through the insights of these supervisors. Policy officials provide essential knowledge about the role of regulations along with government support which shapes technological adoption environments. The study integrates different roles to understand the complete operational and market and regulatory dynamics which influence technology adoption in the mining industry.

Industry Distribution Justification

The study includes representatives from three sectors at equal proportions: 50% from mining and 25% each from government entities and environmental services. The large number of participants from the mining sector enables researchers to examine primary challenges experienced by those operating underground. Government officials bring understanding about how policies and incentives and regulatory frameworks either support or block technological development. The participation of environmental services professionals brings essential knowledge about sustainability and compliance standards that matter significantly to modern mining operations. Multiple viewpoints which reflect the industry complexities become possible through this research approach because it integrates perspectives from various backgrounds.

Sampling Logic and Its Importance

The research methodology utilizes purposive sampling because it allows experts to participate based on their experience with technology adoption and implementation (Sikalumbi et. Al, 2025). This sampling technique generates data that matches the research goals and provides rich information. The research benefits from expert knowledge about barriers and enablers within specific contexts through participant selection. The intentional participant selection method improves the reliability of gathered insights which leads to better comprehension of effective technological adoption strategies for Zimbabwe's underground chrome mining.

Demographic Variable	Description	Sample Size	Percentage
Total Participants	Total number of participants recruited	12	100%
Role			
- Supervisors	Number of supervisors	3	25%
- Policy Official	Number of policy officials	3	25%
- Technology Vendor	Number of technology vendors	3	25%
- Ventilation Specialist	Number of ventilation specialists	3	25%
Gender			
- Male	Number of male participants	7	58%
- Female	Number of female participants	5	42%
Industry			
- Mining	Number of participants from the mining sector	3	25%
- Government	Number of participants from government entities	3	25%
- Technology	Number of participants from technology firms	3	25%
- Environmental Services	Number of participants from environmental services	3	25%
Sampling Logic			
- Method	Description of sampling method used	Purposive sampling	
- Criteria	Criteria for participant selection	Relevant experience in technology adoption and implementation	

Tab 1 Participant demographics

Research Approach

This research examined the barriers and enablers that influence technology acceptance in underground chrome mining operations throughout Zimbabwe through qualitative research methods. The research design suits this study because it enables thorough examination of intricate social cultural and economic elements which influence technology adoption.

Data Collection Methods

Interviews

A set of semi-structured interviews was conducted to collect data from miners together with technology providers and government officials as well as industry experts. This questioning style offers flexibility so participants can explain their experiences along with their perceptions about technological adoption. The interview process made a follow up with open-ended questions which enable the collection of extensive information about:

- Present technological applications used in underground chrome mining operations.
- The obstacles which prevent new technology adoption from happening.
- The systems which promote technology implementation success.
- The function of government policies together with industry regulations.

Data Analysis

Thematic analysis was used to analyze the information gathered through interviews. The analysis process consists of multiple sequential phases as shown below.

Phase	Description
Transcription	All recorded interviews were fully transcribed to ensure accurate data representation.
Systematic Coding	The researcher conducted systematic coding to extract recurring themes and patterns related to technological adoption barriers and enablers.
Initial Code Creation	Initial codes were developed based on research questions and the content of the data collected.
Theme Organization	Multiple codes were grouped into fundamental themes highlighting key findings about technological readiness, financial limitations, and policy effects.
Final Theme Analysis	The researcher examined the ultimate themes to derive findings about sectoral technological adoption factors, offering a detailed understanding of the situation.

Tab 2 thematic analysis

All recorded interviews discussions received complete transcriptions to maintain accurate data representation.

The researcher conducted systematic coding to extract recurring themes and patterns and insights about technological adoption barriers and enablers from the collected data. The research questions and data content guided the creation of initial codes for the study.

Multiple codes were organized into fundamental themes which highlight essential discoveries about technological readiness and financial limitations and policy effects.

The researcher studied the ultimate themes to extract findings about sectoral technological adoption factors which provides detailed understanding of the situation.

Ethical Considerations

The researcher obtained approval from institutional review boards before starting data collection procedures. More so

participants were made to understand study objectives and consent procedures through a consent document.

Time Horizon

The researcher selects a cross-sectional time horizon because it enables the capture of present technology adoption patterns during a particular moment in time. This methodology enables researchers to gather different stakeholder viewpoints which generate immediate relevant information for decision-making purposes. The method proves cost-effective because it allows data collection within a shorter duration than longitudinal research requires. The cross-sectional design strikes an optimal balance between understanding current barriers and enablers and safety impacts in underground mining operations and the practical constraints of time and resources. The main weakness of cross-sectional research according to Saunders and Lewis (2018) is that the collected data represents a specific location and moment in time and event which cannot be extended to a longer period.

Research method and Justification

The research design utilizes sequential exploratory research methods which unite qualitative and quantitative approaches for better understanding. The sequential exploratory research design suits investigations of complex phenomena including technological adoption barriers and enablers in Zimbabwe's underground chrome mining sector. The research design starts with qualitative data collection to obtain deep insights before moving to quantitative data collection for validation and generalization purposes. The sequential exploratory research design provides complete knowledge about research topics because of its strengths. The research began with semi-structured interviews of mine managers and operational staff to gather qualitative data. The qualitative phase seeks to discover detailed experiences and perceptions about technology adoption so the researcher can identify main barriers and enablers specifically within Zimbabwe's mining industry. The research do proceed with a quantitative survey for a wider population in the sector after completing the qualitative phase.

The quantitative sections of the study do verify the interview findings through statistical data to support the research conclusions. The research achieves better understanding through the combination of qualitative insights with quantitative data. The sequential exploratory research design provides an optimal solution to study the distinctive problems that affect the mining sector of Zimbabwe. The research design shows flexibility because it allows adjustments based on initial findings which help maintain relevance and adaptability to industry complexities. The research method seeks to develop strategic decisions and effective practices which do support sustainable mining industry development in Zimbabwe.

Reliability and Validity of Research Findings

The trustworthiness of this study on technological adoption in Zimbabwe's underground chrome mining sector depends on ensuring research findings are reliable and valid and generalizable. The study used standardized procedures which include trained researchers and member checking to verify interpretations with participants and consistent interview guides to enhance reliability. The study achieved validity through data source triangulation and detailed descriptions of the research environment and peer review to detect potential biases. The study utilized detailed contextual information to enable readers to determine how well the findings apply to comparable settings although generalizability in qualitative research focuses on transferability instead of statistical significance. The research methods produced reliable findings which can guide strategic decisions and promote sustainable mining practices.

Findings

The research on technological adoption barriers and enablers in Zimbabwe's underground chrome mining sector uncovered essential findings which explain the current situation. The research reveals the intricate nature of technology implementation while demonstrating how different elements affect this process.

The table below provides an organized summary of essential themes and research findings about technological adoption in Zimbabwe's underground chrome mining industry. The successful implementation of new technologies depends on both infrastructure capabilities and workforce readiness because these elements form the foundation of technological readiness. The assessment of existing infrastructure reveals potential gaps that could hinder progress, while the evaluation of skills and training highlights the need for targeted educational programs to enhance the workforce's competence in utilizing advanced technologies.

The themes of Financial Limitations, Policy Effects, Stakeholder Collaboration, and Education and Training together demonstrate the various obstacles and facilitators that affect technology adoption. Financial constraints affect decision-making through funding challenges and cost-benefit perceptions which restrict investments in technology. The regulatory environment and government backing through policy effects either promote or block technological advancement. The success of overcoming barriers depends on effective stakeholder collaboration between key players. The emphasis on education and training demonstrates the necessity to increase awareness and skill development programs which

will empower workers and stakeholders to create better conditions for mining sector technological advancement.

Theme	Sub-themes/Findings	Description
Technological Readiness	Infrastructure Availability	Assessment of existing infrastructure necessary for technology integration.
	Skills and Training	Evaluation of workforce skills and training programs related to technology use.
Financial Limitations	Funding Challenges	Identification of financial barriers that hinder technology investments.
	Cost-Benefit Perception	Insights into how financial considerations affect decision-making regarding technology adoption.
Policy Effects	Regulatory Framework	Analysis of how existing policies impact technological implementation in the mining sector.
	Government Support	Findings on the role of government initiatives and support in facilitating technology adoption.
Stakeholder Collaboration	Engagement of Key Players	Insights into the importance of collaboration among stakeholders for successful technology adoption.
	Communication Barriers	Exploration of communication challenges that affect stakeholder interactions and technology adoption.
Education and Training	Awareness and Knowledge	Findings on the level of awareness and understanding of technology among workers and stakeholders.
	Educational Programs	Analysis of existing educational initiatives aimed at enhancing technology skills in the mining sector.

Tab 3: Thematic findings

The thematic analysis of barriers and enablers to technological adoption in Zimbabwe's chrome mining sector provides a complete framework to enhance operational efficiency and competitiveness. Industry stakeholders can create specific strategies to create an innovative environment by addressing technological readiness and financial limitations and policy effects and stakeholder collaboration and education and training. These initiatives both enable the successful implementation of advanced technologies and create conditions for sustainable growth and resilience in the mining sector which supports Zimbabwe's economic development.

Barriers of technology adoption in Zimbabwe's underground chrome mining operations

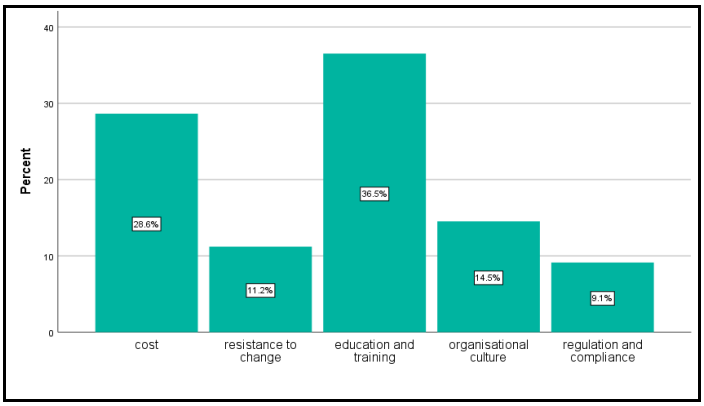

Fig 2: barriers and enablers

Stakeholder interviews together with relevant empirical research and the bar chart data provide additional insights to study technology adoption barriers in the mining sector. The thorough assessment technique creates an extensive understanding of the multiple elements that affect technology adoption.

1. Education and Training (36.5%)

Education and training emerged as the most significant barrier, identified by 36.5% of respondents. This was also substantiated by the results from the interviews where workers expressed that training was the key factor to their resistance against adoption of new technology because they lacked appropriate instruction. One of the respondents said *"Workers lack the understanding about how new technology simplifies their tasks. Employees lack confidence in new technology because they fail to grasp how it can simplify their work" MM.* More so empirical research confirms these results through multiple academic findings which show that inadequate training and education stands as a fundamental obstacle to technological implementation throughout various sectors such as mining (Bhattacharyya, 2022). Chikanda (2021) explains that "education and training needs investment to create skilled workers who can welcome technological changes."

2. Cost (28.6%)

The survey results show that 28.6% of respondents mentioned high costs as their primary challenge. The quantitative results was validated by qualitative insights of some mine personnel who confirmed that the financial strain prevents most companies from adopting new technologies thus according to interview data which includes one participant saying *"The high costs associated with new technology implementation exceed what most of us can afford" **VT.*** The high-cost barriers prevent mining organizations from implementing new

solutions according to the financial assessment. The same sentiment was also picked from research studies that stressed that financial limitations stand as a primary obstacle which hinders technological adoption within mining operations. Ghobakhloo et al. (2022) point out that high costs serve as a major obstacle which prevents various mining operations from acquiring modern technology systems. Research indicates financial aid combined with new funding options represents vital components to overcome this challenge.

3. Resistance to Change (11.2%)

The quantitative survey data indicated that resistance to change stood as a significant issue at 11.2% and can hinder the adoption of technology, the same factor was also picked by some of the participant that described the challenge through these words: *"Many of our workers have fears about new technologies replacing them"* ***MM.*** The difficulty lies in overcoming job-related concerns that create uncertainty in workers. The opposition to technological implementation functions as a substantial obstacle in the adoption process. This barrier was picked by some authors in research studies, and they reiterate that cultural resistance must be dealt with when organizations attempt to implement new technologies. According to Ediriweera et al, (2021) the organizational culture functions as a decisive element which either supports or blocks technological progress. Change management strategies should be implemented because they help reduce fears while creating an environment that promotes innovation.

4. Organizational Culture (14.5%)

The survey data showed that 14.5% of respondents identified organizational culture as a barrier to their work. This was also confirmed by qualitative interviews results that demonstrated that organizations require supportive cultures to succeed. One participant claim that *"Leadership promotion of innovation serves as the only way for employees to feel empowered to embrace organizational changes according to one stakeholder "***(TV)**.This means that leadership holds significant power to establish a workplace environment which supports technological adoption. The empirical research confirms that organizational culture directly affects how quickly technology adoption occurs. According to Naveed (2022), a positive organizational culture that promotes both experimental learning and development stands vital for successful technology integration. Leadership plays a crucial role in developing an innovative work environment through its direct impact on innovation.

5. Regulation and Compliance (0.9%)

The survey data showed that regulation and compliance stood as the least significant barrier to technology adoption since only 0.9% of participants considered it a major challenge. The survey results require further examination to determine their meaning for the overall implementation of technology in Zimbabwe's underground chrome mining operations. More so the survey participants expressed consistent opinions about regulatory stability through one participant who stated *"The government supports technology implementation through favorable policy frameworks." The perception among respondents indicates that regulatory frameworks do not serve as a significant obstacle"* ***PO.*** This was further aided by contributions of the authors who reiterated that regulatory systems differ in their influence on technology adoption across various contexts. Studies show regulatory uncertainty functions as a barrier for innovation (Rossoni, 2024) but Stornelli, (2021) demonstrates how supportive regulations can promote technological advancement. A continuous dialogue needs to exist between mining companies and regulatory organizations.

Enablers of Technology Adoption

Strong leadership along with vision represents the main factor that enables technology adoption in Zimbabwe's underground chrome mining sector. Organizations need effective leadership to push innovation while motivating staff members to adopt new technological solutions. The participants in qualitative interviews identified leaders who actively supported technological integration as the key factors behind innovation development according to the study results. The management's clear demonstration of new technology benefits leads employees to become more open to adopting these systems according to interview findings. Research studies confirm that visionary leadership within organizations creates successful technology implementation outcomes (Akella et al, 2023). Through their leadership approach these executives both establish the foundation for technological acceptance while building spaces which enable employees to successfully transition through change.

The availability of financial resources stands as a vital factor that enables businesses to adopt new technologies. Some participants in the qualitative interviews pointed out financial challenges that mining companies especially small businesses, encounter because these obstacles prevent them from acquiring new technologies. According to this participant *"financial backing is essential for our company to implement advanced technological solution"****MM****.* Research evidence confirms this finding by showing how funding resources such as grants and subsidies support technology adoption (Sahebi, 2021). Companies that obtain financial resources can acquire new technologies and simultaneously fund training programs which prepare employees to master these innovations effectively.

Technology adoption receives substantial enhancement from positive organizational culture because it establishes an environment that supports collaboration alongside acceptance

of change. Research data showed that organizations which involved their employees in decision-making processes encountered reduced obstacles to technology implementation. *"Our active participation in tool evaluation discussions leads to increased personal commitment toward their adoption"**TU.** Empirical studies verify this observation because organizations with supportive cultures perform better in managing technological changes (Usmani, 2023). Through cultural initiatives that promote both innovation and collaboration mining companies create conditions for employee empowerment regarding technology adoption which results in better adoption outcomes.

Discussion

The research findings about technological adoption barriers and enablers in Zimbabwe's underground chrome mining operations show multiple elements that affect stakeholder choices. The adoption of new technologies faces two major obstacles because miners lack training and skills which reduce their confidence and because implementing these innovations costs a lot. The adoption process becomes more complicated because of regulatory challenges which generate uncertainty that drives away investors. The implementation of advanced technologies becomes challenging because limited infrastructure in certain mining areas prevents companies from achieving full innovation benefits. The barriers demonstrate the necessity for specific interventions that can address skill deficiencies and enhance infrastructure quality to promote better technology adoption.

Several enablers emerged which can help overcome the identified barriers. The perceived usefulness of technology emerged as a key factor because stakeholders demonstrated positive expectations about how innovations would boost productivity and safety. Government incentives emerged as essential enablers because supportive policies effectively motivate companies to invest in new technologies. The positive impact of peers who successfully implement new technologies serves as a strong motivator for others to adopt similar approaches. Stakeholders who want to establish an innovative culture in the mining sector need to understand how barriers and enablers interact to achieve operational efficiency and sustainability improvements.

Aspect	Barriers to Adoption	Enablers of Adoption
Management Support	Lack of management commitment	Strong management backing
Regulatory Framework	Inadequate regulations	Supportive and clear regulations
Organizational Culture	Resistance to change	Culture of innovation and openness
Government Intervention	Limited governmental support	Active government incentives
Economic Constraints	High costs of technology	Financial support and funding options
Training and Skills	Lack of training and skills	Comprehensive training programs
Infrastructure	Limited infrastructure	Improved technological infrastructure

Tab 4: Barriers and enablers

Thematic Synthesis

Panackal et al. (2022) study reveals multiple connected themes which provide a detailed comprehension of factors affecting technology adoption across different sectors. The detailed thematic analysis shows that financial limitations emerge as one of the main factors.

1. Financial Constraints

The quantitative data shows cost as the leading barrier for technology adoption with 28.6% incidence. Organizations consistently show worries about funding both the first expenses and continuing expenses for new technology adoption. The expense of adopting new technologies prevents organizations from pursuing innovation particularly when they operate with limited resources.

Enablers: Financial support through grants and subsidies alongside funding options operate as essential enablers. Organizations with these resources can more easily implement new technologies because these assets decrease financial obstacles to adoption. The synthesis demonstrates that a supportive financial environment needs to promote investments in innovative activities.

2. Education and Training

The theme shows that education and training deficiencies cause 36.5% of the problems which demonstrates the essential role of skill development. Many organizations face difficulties because their employees do not possess the required competencies needed to implement and use new technologies.

Enablers: The implementation of extensive training programs stands out as a primary factor that drives progress. Employee education investments from organizations result in a workforce that adapts better to technology adoption thus

lowering resistance. This theme shows the necessity of training programs which both teach new skills initially and provide ongoing learning opportunities to maintain technological progress.

3. Cultural Resistance
Organizations face cultural barriers to adopt new technologies because of change resistance which amounts to 11.2%. The established methods combined with uncertainties about the future create barriers that slow down the progress of new technology implementation.

The success of implementing new technologies depends on organizational cultures which support innovation and flexibility. Organizations that establish open environments which enable employee experimentation and feedback provision can reduce technology resistance and create better transitions to new technologies.

4. Regulatory Framework
The regulatory and compliance factors present only a minor challenge at 0.9% indicating their lower significance relative to financial and educational issues. The process of innovation faces obstacles when regulations become confusing or too restrictive for organizations.

The adoption of technology becomes easier when organizations have supportive regulatory frameworks that provide clear guidelines. Organizations tend to invest in new technologies when innovation receives support through properly designed regulations. The theme demonstrates how policymakers must maintain ongoing communication with industry stakeholders to develop an environment which supports technological advancement. boost their technology adoption capabilities and improve operational performance.

Surprising Finding

Surprising Finding 1: Cost Perception vs. Willingness to Invest
Organizations show willingness to invest in technology when they receive compelling business cases according to the Performance Expectancy construct of ***UTAUT***. The perceived value of technology benefits directly determines the decision to implement new systems according to the Performance Expectancy construct. The study shows that organizations choose to invest in performance improvements despite financial constraints which represent 28.6% of technology adoption barriers. The discovery contradicts some qualitative findings which confirm that financial obstacles can prevent organizations from adopting new technologies. The financial impact of new technologies created significant worry among stakeholders who demonstrated that cost remains an important obstacle for their organizations.

Surprising Finding 2: Positive Past Experiences Reduce Resistance
The second discovery shows organizations which successfully adopted technology in the past experience minimal resistance to change at 11.2% according to the ***UTAUT*** constructs of Social Influence and Facilitating Conditions. Social Influence describes how people perceive others' expectations about their adoption of new systems. Organizations develop positive social environments through successful experiences which create a culture that welcomes change. The resources and support systems which help technology use fall under the category of Facilitating Conditions. Previous successful technology implementations create a base of support and resources which decreases the obstacles to new technology adoption. The discovery shows that successful past technology adoption creates a strong foundation for future acceptance which builds a better organizational culture while decreasing resistance.

Theoretical implication of surprising findings

The study's unexpected results about organizational financial constraints and reduced change resistance after successful technology adoption have important theoretical implications for UTAUT and other technology adoption models. The study's findings about value perception surpassing cost concerns indicate that current frameworks need to develop better methods for analyzing organizational benefit-cost assessments of technology adoption. Theoretical models need to include cultural and historical contexts because positive past experiences reduce resistance to change. The study demonstrates the need for research to analyze how organizational narratives, and social dynamics influence technology attitudes which requires a reevaluation of Social Influence and Facilitating Conditions constructs to better capture temporal and relational aspects of technology adoption.

Thematic map

A thematic map functions as a specialized visualization tool which displays spatial data variations to show specific themes (Christou, 2022) thus making it essential for the study. The map demonstrates the distribution of AI and IoT technology enablers and barriers which helps to understand their effects on decision making and safety

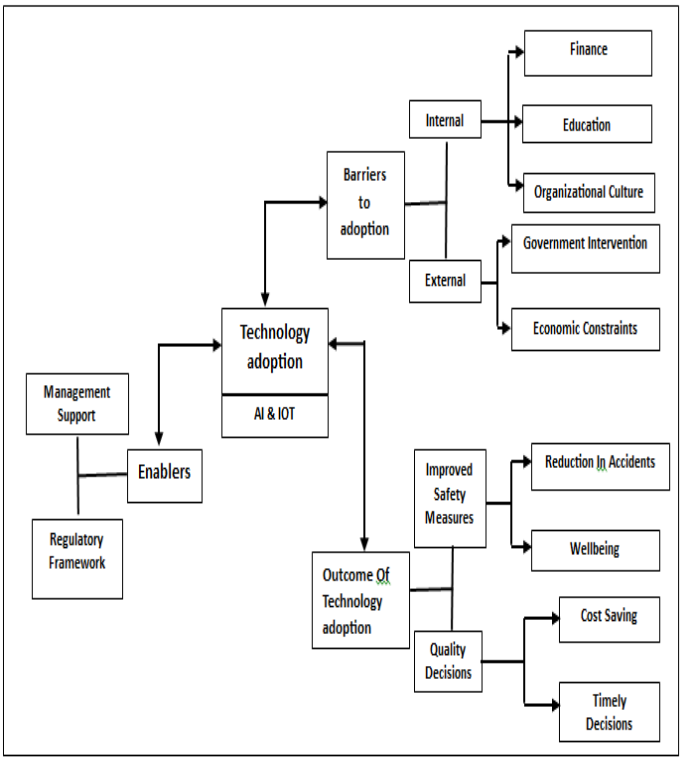

Fig 3: Thematic map

The map presents the elements that affect technology adoption by showing barriers alongside enablers. The adoption of artificial intelligence (AI) and Internet of Things (IoT) technologies receives support from three main enablers which include management backing and strong regulatory systems and government participation. The adoption barriers consist of two categories which include internal organizational culture and external economic limitations. The barriers create obstacles that prevent successful technology implementation across different sectors.

The successful implementation of technology produces multiple beneficial results which include better safety protocols and improved wellbeing together with cost reductions and quick decision-making capabilities. The benefits of technology adoption enhance organizational efficiency and effectiveness thus demonstrating why both enablers and barriers need attention to create an optimal adoption environment. Organizations that understand these dynamics can achieve better results in their efforts to implement new technologies.

Implications for Strategic Decision-Making

The analysis of barriers and enablers provides critical information for strategic decision-making in the mining sector. Companies need to make workforce training and development their top priority to solve skill gaps and boost employee confidence in new technology use. Companies can lower technology investment risks through innovative funding solutions that provide financial support. A workplace culture that supports innovation and collaboration enables employees to become active participants in technology adoption. Stakeholders who implement strategic approaches to overcome barriers while utilizing enablers can boost their technological capabilities which lead to productivity growth and sustainability for Zimbabwe's underground chrome mining sector.

Conclusions and Recommendations

The analysis of barriers to technology adoption in Zimbabwe's underground chrome mining sector shows multiple factors which stakeholders need to handle. The analysis shows that education and training, cost, and cultural resistance are major barriers but the perception of regulation and compliance as a minor issue indicates a generally supportive regulatory environment. The combination of survey data with qualitative findings and academic research confirms that stakeholders should focus on solving major obstacles while keeping good relationships with regulatory organizations. Stakeholders who focus on workforce training and financial support and innovation culture development can boost advanced technology adoption which leads to better productivity and sustainability in the mining sector. The research shows that a complete strategy must address current obstacles while using the identified enablers to create a future-oriented approach for technological integration in this essential industry.

Research limitations

The main issue with this study is the small sample size which may not be representative of all companies and regions in the sector. The qualitative data collected through interviews is subjective and may introduce biases which can affect the interpretation of the results. The temporal context of the study may also influence its relevance, as changes in economic and regulatory environments could alter the landscape of technology adoption. The focus on specific barriers and enablers may not capture broader factors, such as environmental considerations or global market trends. These limitations highlight the need for future research to adopt a more holistic approach and to conduct longitudinal studies that track changes over time, which can enhance the applicability of findings and inform practical strategies within the mining sector.

Originality/value

The research delivers substantial worth to different stakeholders in Zimbabwe's underground chrome mining

industry by examining all barriers and enablers to technology adoption.

The research reveals essential obstacles including education and training issues and financial limitations and cultural opposition which help organizations develop strategic plans. The paper demonstrates how regulatory support combined with active regulatory body engagement drives technological progress. The research recommendations offer specific strategies which mining companies and policymakers and educational institutions can use to develop innovative practices and enhance workforce preparedness. This approach delivers better productivity and operational efficiency while supporting sustainability in mining operations. The research findings expand the global discussion about technology adoption in resource-intensive industries by providing a model that other contexts can use. This paper functions as a valuable resource to create meaningful change while supporting the long-term competitiveness of the mining sector in Zimbabwe.

The research findings present both the elements that affect technology adoption and a strategic planning framework. The research shows executives how to develop organizational cultures that support innovation through their leadership roles. The framework functions as a strategic guide for organizations that want to improve their technological capabilities by matching their initiatives to mining sector realities. The research delivers practical guidance which enables stakeholders to make strategic decisions that boost operational performance and sustainable growth in the industry.

Recommendations

The underground chrome mining sector in Zimbabwe can achieve successful technology adoption through complete training programs. The training programs should develop specific skills which enhance both hard and soft competencies. Educational institutions must work together to establish specific training curricula that address mining industry requirements. Continuous professional development programs should exist to promote lifelong learning which maintains employee proficiency in current technologies and adaptability to changing industry requirements.

Financial support mechanisms require enhancement to address the obstacles which prevent technology adoption. Stakeholders need to promote funding mechanisms including grants and low-interest loans which target technology investments for the mining sector. The collaboration between public and private organizations helps distribute financial costs which allow mining companies of all sizes to obtain advanced technologies. The adoption of technological innovation becomes more likely when government policies establish tax incentives for technology investments which reduce financial risks for companies.

The success of technology integration depends on organizations developing an innovative workplace culture. The adoption of technology depends on leadership support and engagement from employees. Employee involvement in technology decisions can decrease opposition and create feelings of possession about technological progress. A safe workplace that enables employees to share their worries and input suggestions can help achieve a better implementation of new technologies.

The adoption process can become simpler through strategic change management approaches. Organizations must provide employees with full information about technological benefits and goals to achieve successful adoption. The organization should resolve employee fears regarding job stability through explanations about technology capabilities to improve their work responsibilities. The implementation of support systems including mentoring and coaching helps employees transition better to new technologies thus creating positive reception and better integration.

Active engagement with regulatory bodies needs continuous maintenance for building a favourable environment that supports technological progress. Ongoing discussions help develop mining sector-specific regulations while feedback channels enable companies to communicate compliance issues to authorities. All stakeholders who work together to share their best practices can build a supportive environment for innovation which leads to better productivity and sustainability in the mining industry of Zimbabwe.

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