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Challenges Faced by Mining Organisations in Implementing Digital Solutions for Improving OSH Compliance

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Abstract

The study aimed to identify key challenges faced by mining organizations in implementing digital solutions for improving OSH compliance. This study deployed a mixed-methods approach with a crossectional survey desing in which case data were collected across the randomly selected major mines from different sources. Primary data were collected using online surveys from 198 top managemnt and 586 employees who were proportionately randomly selected, and semi-structured interviews with 20 key informants. Secondary data were collected from official documents and previous studies. Quantitative data were analysed using descriptive statistics in term of composite means scores, and Multiple Correspondence Analysis (MCA) method. All statistics and plots were generated by R version 4.3.2. Qualitative data were analysed using the thematic analysis methods following the The Braun and Clarke (2006) six stages.

The study found that challenges including the lack of employee digital skills, and the lack of OSH subcommittees, cut across all major mines regardless of the digital implementation maturity level. The other two challenges namely financial constraints and lack of commitment are highly associated with major mines with low and medium digital implementation maturity.

However, the challenge of financial constraints, the lack of commitment, and technical limitations affect adoption decisions mainly at the entry and early phases of digital implementation. However, the lack of employee digital skills and OSH subcommittees jeopardize the potentiality of digital tools. These two challenges seem to affect the usage of digital tools, and the overall involvement of the workers in a more decentralized manner.

Keywords: *Digital Transformation, Implementation of Digital Tools, Challenges facing Implementation of Safety Digital Tools, OSH Digitalization Challanges in Major Mines.*

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1.0 INTRODUCTION

The mining sector is crucial for Tanzania's economy, significantly contributing to employment, exports, and national income(Lyatuu *et al.*, 2021). According to the 2020 Tanzania National Bureau of Statistics report, the mining sector contributed around 5.1% to the country's GDP and employed over 100,000 workers.

According to Floris (2014) mining sector is said to be an inherently hazardous industry, with workers facing dangerous conditions that lead to accidents, injuries, and even death. Protecting workers' health and safety, maintaining productivity, and promoting socially and ethically acceptable behaviors all depend on this industry's dedication to Occupational Safety and Health (OSH) standards. Despite efforts to enforce safety regulations, the challenges persist especially in large-scale operations where maintaining consistent oversight is seem to be difficult (Pagell *et al.*, 2013). According to Boniface (2013), the mining industry in Tanzania has experienced an average of 120 work-related accidents per year, including 15 fatalities, over the past 5 years across major mining operations. Moreover, the informal artisanal mining industry presents much greater health and safety hazards, characterized by inadequate monitoring and compliance (Smith *et al.* 2016)

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Digital transformation has been realised as the strategy to tackle these difficulties. Technologies include digital sensors, real-time data analytics, automated monitoring systems, and mobile apps have shown the capacity to improve occupational safety and health compliance by facilitating superior tracking, reporting, and administration of safety standards. These solutions has been a key to enhance danger identification, optimize operations performance, minimize manual labour, and cultivate a safety-oriented culture inside mining facilities. Despite the considerable advantages of digital technologies, their implementation in Tanzania's mining industry is restricted, and there is a lack of comprehension of their effects on occupational safety and health compliance due to resource-limitation.

The application of digital technologies has emerged as a promising approach to address the challenges in occupational safety and health compliance within the mining sector. According to Kinyondo innovations such as digital sensors, real-time data analytics, automated monitoring systems, and mobile applications have demonstrated potential to enhance OSH compliance by facilitating improved tracking, reporting, and management of safety protocols. These digital tools not only enhance hazard detection but also streamline processes, reduce manual work, and foster a culture of safety within organizations. However, while these digital solutions offer substantial benefits, their adoption in Tanzania's mining sector remains limited, and there needs to be a more comprehensive understanding regarding the implementation challenges, particularly in resource-constrained environments (Kinyondo & Huggins, 2021). The primary mining sector in Tanzania is the focus of this paper which aimed to identify key challenges faced by mining organizations in implementing digital solutions for improving OSH compliance.

2.0 LITERATURE REVIEW

Among the eastern sub-Saharan African countries, Tanzania is well-known for its mining industry. The mining sector is an important part of the country's economic strategy, and the government has taken steps to improve its efficiency and effectiveness, such as instituting new rules to protect workers' health and safety on the job through OSH regulation governed by the Occupational Safety and Health Authority. However, the enforcement and implementation of these regulations remain a challenge, with high rates of work-related injuries and fatalities still being reported in the mining sector (Stemn, 2018). Therefore, this research will assist the Government and mining sectors the challenge but again to be assure if the digital adaptation on OHS add value on compliance in Tanzania.

The study was guided by the Socio-Technical Systems Theory that can be traced far back in the early 19th C. In the 1940s, Eric Trist, Ken Bamforth, and Fred Emery conducted research at the Tavistock Institute on coal mining operations in England, which led to the development of Socio Technical Systems Theory (STS) (Trist & Bamforth, as referenced in Long, 2013; Stranks, 2007). Later, STS was expanded to emphasize the joint optimization of technological and social systems through wider applications in organizational development. In sophisticated settings, such as the case of OSH digitalization in the mining sector, the contemporary STS combines the human-machine interfaces and cybernetic processes altogether (Long, 2013; Cardenas & Kozine, 2025). One of the fundamental tenets of STS is the joint optimization principle, which maintains that for the system to function effectively as a whole, neither the technological nor the social subsystem should predominate (Cardenas & Kozine, 2025). The theory makes the assumption that people, technology, tasks, and environment interact to produce work results, and that when these factors are taken into account together, organizational performance is maximized (Long, 2013).

In the context of this study, the theory suggests a focus on challanges merging from the tecnical subsystems and those from the organizational subsystems. Based on this context the study focused on technical limitaions, digtal skills, OSH comiitees and workers engagements, financial barriers, and regulatory problems.

However, some critiques argue that STS treats socio-technical systems as neutral rather than politically embedded, undervaluing the institutional pressures and power dynamics influencing technological adoption – in this case the OSH digitalization (Geels et al., 2019). More specifically, actor-centric perspectives are criticized by Munir (2020) for failing to recognize ingrained structural privilege and normalized discourses. While acknowledging the weight of this argument, the study focuses on major mines in one country in a scenario where institutional pressure is necessarily assumed to be common or equally distributed to all major

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mines operating under one and common legal framework, and political atmosphere. This context provides the study with enough room to utilize the STS theory with confidence and also add external validity to the study findings should the generalization conditions suffice one country, common legal and policy frameworks at national level.

3.0 METHODOLOGY

This study deployed a mixed-methods approach where qualitative data regarding the digital transformation and quantitative data regarding challenges were used altogether. Thus, cross-sectional survey desing was adopted in which case data were collected across the selected major mines from different sources. The study was conducted in Tanzania and involved six major mines out of the existing operational 8 major mines [Figure 2.1]. The population of the study included the top managemnt and employees from six major mines tha were randomly seleted. The study relied on multistage sampling methods with simple random sampling at each stage starting with selecting major mines, followed by sampling top management, and then sampling the overall staff. At the first stage six major mines including Geita Gold Mine, Bulyanhulu Gold Mine, Williamson Diamond Mine, Buckreef Gold Mine, New Luika Gold Mine, and Ngaka Coal Mine were selected.

The second stage involved sampling the 232 top management using stratified random sampling. The top management was treated as separate sample to analyse the level of digital transformation across the major mines. Thus, top management was selected from each major mine in this case regarded as sampling cluster using stratified random sampling respective of the sample proportion. This method ensured that sample was adequate and representative to answer the research question regarding the current state of adoption of digital transformation. The same procedure was followed for selecting 594 staff from major mines across departmets and sections. At the end of the study 198 top management staff which is equivalent to 85.3%, and 586 overall staff which is equivalent to 98.6% responded.

Qualitative data were collected through the semi-structured interviews with 2 safety officers including the head of safety officers who is also the head of the Safety Committee, 1 ICT manager for each of the six major mines, and from 2 OSH Authority representatives including 1 Principal ICT Officer with 17 years of working experience, and 1 Safety Engineer with relevant field and administrative experience in OSH and the ongoing digital transformations. On the other hand quantitaive data were collected from 198 top management staff and 586 overall staff who were randmly seletced from the six major mines using questionnaires.

Nontheless, secondary data were collected from official documents including the implementation plans specifically for safety digital tools, procurement reports, and safety reports, and the literature review of previous studies and digital transformation resources (Innotech, 2021; Mipac, 2022; Johnston, 2017). Qualitative data were analysed using the thematic analysis methods following the The Braun and Clarke (2006) six stages. Quantitative data were analysed using descriptive statistics in term of composite means scores, and Multiple Correspondence Analysis (MCA) method. In this case the statistical analysis software namely R version 4.3.2 was used.

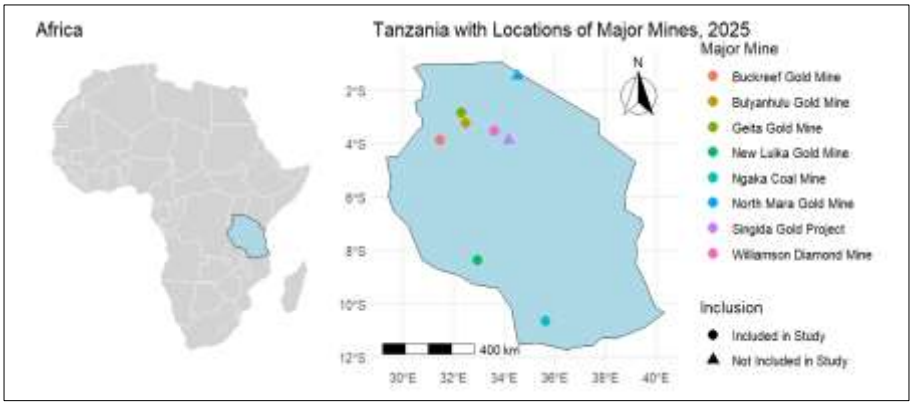

Figure 2.1 Locations of Tanzania Major Mines, 2025

4.0 RESULTS AND DISCUSSIONS

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The study aimed to identify key challenges faced by mining organizations in implementing digital solutions for improving OSH compliance. The study relied on descriptive analysis mainly the Multiple Correspondence Analysis (MCA). To safeguard a biplot approach, to display both major mines and associated challenges the mines are categorized into three categories based on digitalization scores. The results are presented in the order of profile of major mines included in the study, digital transformation, categorization of major mines by maturity level of implementation of digital tools, and multiple correspondence analysis.

4.1 Profile of Major Mines Included in the Study

The profile of major mines includes the overall characteristics in terms of mine type, origin or ownership, mineral type, capital expenditure, operating expenditure and size by number of employees.

Table 3.1: Summary Statistics of the Studied Major Mines

Major Mine	Mine Type	Origin/ Ownership	Mineral	Capital Expenditure (Year)	Operating Expenditure / oz (Year)	Number of Employees
Geita Gold Mine	Mixed	Foreign	Gold	-	$944 (2024)	3150
Williamson Diamond Mine	Open-pit	Mixed	Diamonds	$35 M (Q1 2025)	$1,714 (Q1 2025)	1470
Bulyanhulu Gold Mine	Underground	Foreign	Gold (& Ag, Cu)	-	-	1460
Ngaka Coal Mine	Open-pit	Mixed	Coal	-	-	1304
New Luika Gold Mine	Mixed	Foreign	Gold	$25 M (2023)		1203
Buckreef Gold Mine	Open-pit	Foreign	Gold	$196 M (2024)	$984 (2024)	1007
Source: Administrative Data, 2025						

The study included six major mines, 3 of them are open-pit, 2 are mixed and 1 is undergoing. Four of them were foreign owned, 2 were co-owned by foreign and Tanzania government. Gold is the major focus of major mines in Tanzania where 4 are dealing with gold, the remaining 2 are dealing with either diamonds or coal. The rankings of these mines by size are not clear with financial data such as capital expenditure and operating expenditure, owing to lack of adequate data. However, based on the number of employees, Gita Gold Mine is regarded the largest with 3150 employees and the smallest is Buckreef Gold Mine with 1007 employees. In a broad view, the study included a diversity of major mines with respect to mine type, mineral type, ownership, and size as indicated by number of employees. This improves the external validity of the study findings (Creswell & Creswell, 2018), it also reflects that bias from homogeneous sampling was controlled (Bryman, 2016), and therefore the study findings are grounded in practical realities (Patton, 2015).

4.2 Digital Transformation in Major Mines

The overall state of digital transformation was assessed using qualitative data from key players in OSH and related ICT personnel across the major mines and the Tanzania OSH Authority. The themes that were defined from thematic analysis show that the digital transformation of the six major mines ranges from digital incident reporting systems, real-time safety monitoring systems, automated hazard detection systems, digital safety training platforms, and safety compliance tracking software. The details are presented in Figure 3.1.

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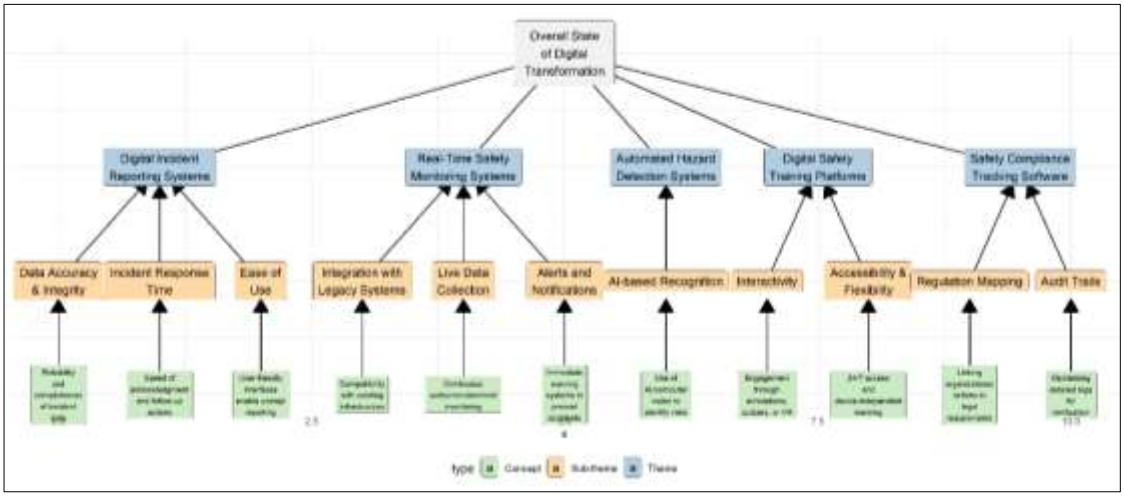

Figure 3.1: Thematic Maps
Source: Semi-Structured Interviews, 2025

The results in Figure 3.1 indicate a significant step toward ongoing proactive, and data-driven safety management using the digital OSH systems. However, the details on the level to which the safety digital tools are implemented deduced from survey results show varying levels across these indicators. This finding is supported from further analysis comparing implimentation levles for different safety digital tools. The respective survey results are presnted in form of frequences and percentages in Table 3.2.

4.3 Categorization of the Major Mines by Implementation Level

Major mines are categorized based on the digitalization scores referred to as the implementation maturity levels. This was a composite score for the five indicators including digital incident reporting systems, real-time safety monitoring systems, automated hazard detection systems, digital safety training platforms, and safety compliance tracking software. The top management [N=198] was asked to rated a five-point Likert scale was used with 1=Not implemented, 2=Planning stage, 3=Partially implemented, 4=Fully implemented, 5=Fully implemented and optimized, for each of the five indicators. The composite score was estimated as the average score of the five indicators. Normality test was performed to inform the study on consistent measure of central tendency. The Shapiro Wilk test of normality show that the distribution of digitalization scores was not coming from normal distribution across all major mines. The results are presented in Figure 3.2.

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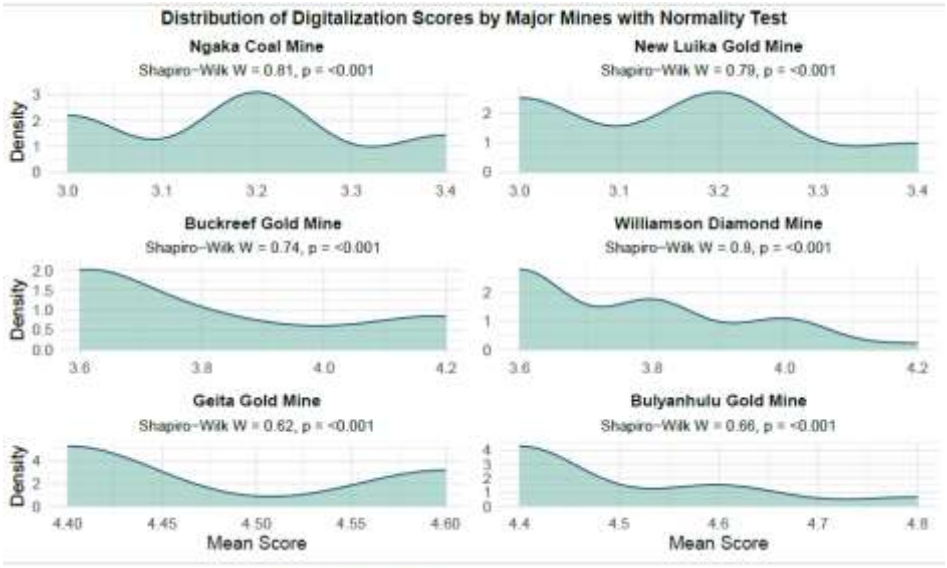

Figure 3.2: Shapiro Wilk Test of Normality
Source: Survey Data, 2025

The results in Figure 3.2 show that digitalization scores were not following normal distribution across Bulyanhulu Gold Mine (Shapiro Wilk Statistics = 0.66, p-value<0.001), Geita Gold Mine (Shapiro Wilk Statistics = 0.62, p-value<0.001), Buckreef Gold Mine (Shapiro Wilk Statistics = 0.74, p-value<0.001), Williamson Diamond Mine (Shapiro Wilk Statistics = 0.8, p-value<0.001), Ngaka Coal Mine (Shapiro Wilk Statistics = 0.81, p-value<0.001), and New Luika Gold Mine (Shapiro Wilk Statistics = 0.79, p-value<0.001). Based on the lack of normal distribution the study relied on median score for comparison and categorization. Median is preferred for consistency in case of non-normal distribution compared to other measures like the mean score (Bland, 2015). The results are presented in Table 3.2.

Table 3.2: Categorization of Major mines by Median Score

Major Mine	Number	Min	Median	Max	IQR	Level
Bulyanhulu Gold Mine	30	4.4	4.4	4.8	0.2	High
Geita Gold Mine	41	4.4	4.4	4.6	0.2	High
Buckreef Gold Mine	31	3.6	3.6	4.2	0.4	Medium
Williamson Diamond Mine	27	3.6	3.8	4.2	0.2	Medium
Ngaka Coal Mine	37	3	3.2	3.4	0.2	Low
New Luika Gold Mine	32	3	3.2	3.4	0.2	Low

Source: Survey Data, 2025

4.4 Multiple Correspondence Analysis of the Challenges

The data for analysing challenges were obtained through the cross-sectional survey where 586 respondents from all sections and departments of respective major mines who were sampled randomly with proportional to strata size. The Multiple Correspondence Analysis (MCA) was used to uncover the linkages and underlying structure of the identified challenges across six major mines. MCA is regarded a relevant approach since the challenges are identified using binary indictor of Yes/No. (Leroy et al., 2022; Silva et al., 2021). The input data comprised five challenges including lack of OSH subcommittees (Yes = 39.1%, N = 586), lack of employee digital skills (Yes = 39.4%, N = 586), financial constraints (Yes = 37.5%, N = 586), technical limitations (Yes = 37.2%, N = 586), and lack of leadership commitment (Yes = 24.1%, N = 586). The results are shown

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in the Figure 3.3 which is a biplot of both the challenges and the six major mines as points in a two-dimensional space.

Figure 3.3: Visualization of the MCA Results
Source: Survey Data, 2025

The results in Figure 3.3 show that there are five main challenges facing major mines in implementing digital tools for OSH. The level at which these challenges affect the implementation varies across major mines. At the center of the plot lies two challenges, the lack of employee digital skills, and lack of OSH subcommittees, indicating they cut across all mines almost equally regardless of the digitalization level. The other two challenges namely financial constraints and lack of commitment are very close to major mines in low and medium digitalization levels. On the other hand, the challenge of technical limitation is much closer to mines with medium digitalization level compared to the rest. The findings imply that financial constraints, the lack of commitment, and technical limitations which seem to be far distant from major mines with high digitalization levels affect adoption decisions mainly at the entry and early phases of digital implementation. Also, the findings imply that at any level of digitalization the challenges of lack of employee digital skills and OSH subcommittees jeopardize the potentiality of digital tools. These two challenges seem to affect the usage of digital tools, and overall involvement of the workers in a more decentralized manner. Further discussion of the challenges in the next subsections.

4.5 Discusion

Financial Constraints

The study findings show that financial constraints negatively affect the level of digital implementation for OSH in major mines. This challenge is common in mines with lower or medium digitalization scores indicating high initial investment costs required for advanced OSH technologies and supportive infrastructural upgrade needs. This aligns with a recent study showing that financial constraints and infrastructural barriers as intertwined factors affecting adoption of digital health and safety in the construction sector of the developing regions (Daniel et al., 2024). However, this study revealed that similar challenges may affect operational and ongoing activities such as employee digital training as part of the operational expenditures even for major mines with high digitalization scores. The finding is in agreement with Tonkin (2025), who found that in Australia a huge mining entity, Northern Star Resources had spent over A$50 million for staff training to gain technical competence relevant with high tech tools for maximum OSH in high-risk sections of the mines. The findings imply that even the biggest mines like Geita Gold Mine and Bulyanhulu with high digitalization scores face considerable operational costs associated with digital OSH in terms of maintenance and repair,

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training. This finding adds useful insight into why the lack of employee digital skills is approximately equally cutting across all mines regardless of the digitalization level.

Lack of Employee Digital Skills

The lack of employee digital skills is a challenge further rooted in financial constraints as part of the ongoing operational costs. This challenge is common in all major mines included in this study irrespective of the digitalization level. The study found that over 48.1% (N=586) of employees lack digital skills across the six major mines. This figure is above the 34% of mining professionals lacking digital transformation in the Russian mining sector (Logicalis Global CIO Survey & Natural Resources Research, 2019). The findings indicate that employee digital skills is a very crucial element of digital OSH implementation through high confidence in automated system, and adaptability all of which associated with effective digital usage, and minimized risk of digital misuse (Dodoo et al., 2024). In a contrasting quadrat, the lack of employee digital skills affects implementation of digital tools at the acceptance level, orientation level and at the usage level (Dodoo et al., 2024; Lephotlo & Khatleli, 2021).

Lack of Commitment

Management commitment to OSH digitalization is a critical aspect of effective implementation. The study found that major mines in lower and medium digitalization levels were closely confined within the same quadrant of lack of management commitment. Thus, high level of commitment for the major mines with high digitalization levels seem, at least partly, to be a distinguishing factor for fully implemented and optimized digital tools. The core role of management commitment is linked to decision making, priority setting, enabling of policy and accountability all of which are vital given the financial constraints (Lephotlo & Khatleli, 2021).

Technical Limitation

Technical limitation as a challenge to implementation of digital OSH programs was common across mines in medium digitalization level. These mines have moved from partial implementation but fail to optimize their digitalization due to technical limitations. Mines that have relatively, or at least comparatively overcome similar challenges have fully implemented and optimized digital tools for OSH. The finding suggest that the challenge of technical limitation is further rooted in financial constraints owing to the fac that advanced technologies are relatively expensive to adopt and operate (Sithole, 2024). The study findings show that some of the common aspects of technical limitations include lack of system compatibility, outdated software, and poor connectivity mainly for underground sections of major mines. However, despite this study showing technical limitations are common in medium and lower digitalization phases, other studies provide evidence in the opposite direction. A study that was conducted in Italy and Finland show that smart garment sensors in both underground 350m deep and open pit were significantly inaccurate (Sorribes-Palmer et al., 2024). This implies that suboptimal technical sophistication in digitalizing OSH initiatives cannot be considered free from common technical challenges facing mining sector.

Lack of OSH Subcommittees

The inherent structure of workers engagement is limited to a centralized overall OSH committee imposing a top-down approach associated with poor workers engagement. The study found that the lack of OSH subcommittees across sections and departments within the organization of major mines was of critical concerns. The first concerns is limited opportunity for expertise participation from respective departments and sections in design and management of OSH programs. The sections and departments in mining sector are characterized with a diverse of scope and complexity of OSH needs. The lack of decentralized renders the current OSH programs with more of ad hoc nature, as they lack a holistic view both in design, and monitoring and evaluation. A study by Schnall et al. (2022) found that exclusion of employees in design and decision-making hampers Internet of Things based OSH. The findings also align with Liang et al. (2024) as they found that the lack of workers participation in scaling up or rollout of digital platforms is a major barrier to implementation of digital OSH.

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5.0 CONCLUSION

The study found five main challenges facing the implementing digital tools for OSH across major mines. the challenges include financial constraints, lack of commitment, technical limitations, the lack of employee digital skills, and lack of OSH subcommittees.

The level at which these challenges affect the implementation varies across major mines. Two challenges namely the lack of employee digital skills, and lack of OSH subcommittees, cut across all mines almost equally regardless of the digital implementation maturity level. The other two challenges namely financial constraints and lack of commitment are highly associated with major mines with low and medium digital implementation maturity.

On the other hand, some challenges including financial constraints, the lack of commitment, and technical limitations affect adoption decisions mainly at the entry and early phases of digital implementation. However, the lack of employee digital skills and OSH subcommittees jeopardize the potentiality of digital tools. These two challenges seem to affect the usage of digital tools, and overall involvement of the workers in a more decentralized manner.

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