Scholarly Journal of Science and Innovation

SJSI 2025, Volume 5, Issue 8, Page 78-92
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Journal Impact Factor (JIF): 8.871
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ISSN: 2676-2714
DOI: https://dx.doi.org/10.64839/sjsi.v5i8.5
web: https://damaacademia.com/index.php/sjsi/

The Impact of The Implementation of Digital Tools on Occupational Safety and Health Compliance

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Abstract

This study is uniquely deviating from previous studies and focused on the impact of digital transformation on OSH compliance in the context of the mining sector in developing country. The study gains its weight in the country like Tanzania where occupational risks in mining sector are a major concern coupled with paucity of empirical evidence regarding the way forward. The study findings extend the knowledge frontier to the understanding of extent to which digital tools can greatly improve OSH compliance especially when they are effectively implemented with a more holistic approach.

This study deployed a quantitative 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. Secondary data were collected from official documents and previous studies. Quantitative data were analysed using descriptive statistics in term of frequencies, percentages, and composite means scores generated by R version 4.3.2.

The study found that implementation level of safety digital tools impacts OSH compliance positively [Average Marginal Effect (AME) = 0.3336, p-value<0.001; 95% CI = 0.323 - 0.344]. Other factors include training effectiveness [AME = 0.0175, p-value<0.001; 95% CI = 0.0114 - 0.0235], and the usage of digital tools [AME = 0.149, p-value<0.001; 95% CI = 0.141 - 0.156]. Higher potential is subject to the adressing of financial constraints, ill-commitment, technical limitations, the lack of employee digital skills, and lack of OSH subcommittees.

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

Citation: *Machary, M. R. (2025). "The Impact of The Implementation of Digital Tools on Occupational Safety and Health Compliance", Scholarly Journal of Science & Innovations, 2025, 5(8): pp.78-92. DOI: https://dx.doi.org/10.64839/sjsi.v5i8.5*

Submitted: 01 June, 2025 | Accepted: 20 August, 2025 | Published: 12 October, 2025

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 their impact on OSH compliance, particularly in resource-constrained environments (Kinyondo & Huggins, 2021).

The primary mining sector in Tanzania is the focus of this paper, which aimed to assess the current state of digital adoption. The paper aimed to provide data-driven insights that may guide policy choices and make it easier to integrate solutions that are based on technology. This research aimed to improve mining safety standards in Tanzania by highlighting how digital transformation may lead to better industrial safety measures.

2.0 LITERATURE REVIEW

The study was guided by the Socio-Technical Systems (STS) Theory, and the Technological Acceptance Model (TAM). The STS 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).

On the other hand, the TAM was first propounded by Fred D. Davis in 1986 and later it was jointly formalized by Fred D. Davis, Richard P. Bagozzi, and Paul R. Warshaw, in the year 1989. TAM was initially broadly founded in the Theory of Reasoned Action before being condensed to concentrate on two main ideas namely perceived usefulness and perceived ease of use (Davis et al., 1989). According to TAM perceived usefulness and perceived ease of use determines the use of technology. The model posits that the actual usage of technology is a function of behavioral intentions that mapped through perceived usefulness and ease of use for a given technology. As a result of this strong axiom, TAM suggests that the degree of digital tool usage needs to be regarded as a mediating variable between implementation of digital tools and OSH compliance.

These two theories work in tandem to describe the behavioral mechanisms influencing the use of digital tools and the systemic integration of these tools into mining operations, both of which have an impact on OSH compliance. The broad macro perspective provided by STS examines the interactions between mining companies, their technologies, employees, and overall environment signifying legal frameworks, policies and mandates (Coiera, 2007). On the other hand, according to perceived qualities, training, social context, and experience, TAM offers the micro foundation for how people embrace and use digital products (Venkatesh et al., 2003; Hendricks et al., 2023).

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In actuality, STS presents the use of digital tools as a component of a broader sociotechnical framework that influences OSH compliance. Then, TAM explains why people in that system may or may not use those tools. For instance, according to STS, a well-integrated digital monitoring system only improves compliance if the social subsystem—which includes users, training, and norms—aligns. With moderators like experience and mine type, TAM assists in defining whether users desire to use the system and do so based on perceived usefulness, perceived ease of use, or effort expectancy, as well as facilitating conditions (Hendricks et al., 2023; Venkatesh et al., 2003).

By combining these theories, the study was designed on a cohesive conceptual and empirical model, with TAM directing usage behavior measurement and hypothesis testing and STS directing the research design and contextual variables. Systemic insight and behavioral specificity are made possible by the combination, which also allows for the discussion of technical-social alignment (Dodoo et al., 2024; Hendricks et al., 2023).

3.0 METHODOLOGY

This study deployed a quantitative approach where quantitative data regarding implementation of digital tools, and OSH compliance were of main concern. 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. 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). Data were analysed using descriptive statistics in term of frequency, percentages, composite means scores, and regression analysis. In this case the statistical analysis software namely R version 4.3.2 was used.

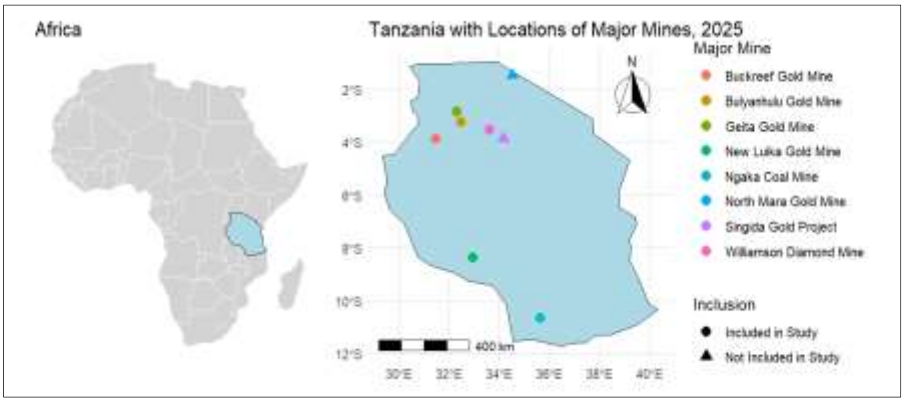

Figure 2.1 Locations of Tanzania Major Mines, 2025

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4.0 RESULTS AND DISCUSSIONS

The study aimed to evaluate the impact of the implementation of digital tools on occupational safety and health compliance. The study applied a two-stage approach where the first stage focused on identifying the level of implementation of digital tools among the selected big mining companies, and to specify the model in for evaluating the impact of the implementation of digital tools on occupational safety and health compliance. The results are presented in the order of profile of major mines included in the study, exploratory analysis, and multivariate regression analysis.

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).

4.1 Exploratory Data Analysis

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 3.1.

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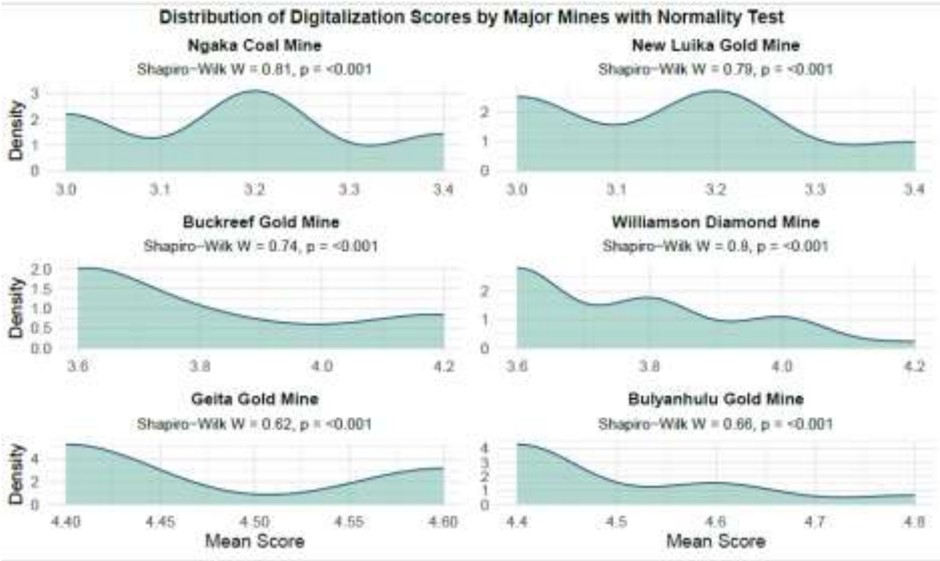

Figure 3.1: Shapiro Wilk Test of Normality

The results in Figure 3.1 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: Implementation Median Score of Major Mines (Survey Data)

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

Source: Survey Data, 2025

Table 3.3: Five-point Scores on Documented Digital Tools Implementation

	Indicators on Digital Tools Implementation Status					
Major Mine	Digital Incident	Real-Time Safety	Automated Hazard	Digital Safety	Safety Compliance	Average

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	Reporting Systems	Monitoring Systems	Detection Systems	Training Platforms	Tracking Software	
Geita Gold Mine	5	4	4	5	5	4.6
Bulyanhulu Gold Mine	5	3	4	5	5	4.4
Williamson Diamond Mine	3	3	2	3	5	3.2
Buckreef Gold Mine	3	3	3	2	5	3.2
New Luika Gold Mine	2	2	3	3	3	2.6
Ngaka Coal Mine	3	3	2	2	3	2.6
Average	**3.5**	**3.0**	**3.0**	**3.3**	**4.3**	**3.4**

Source: Administrative Data, 2025

The scores in Table 3.3 show that the mines can be categorized in those with relatively high score of 4.4 and 4.6, medium score of 3.2 and low score of 2.6. The results suggest that the data from primary source and secondary sources yield common general conclusion in terms of categorization despite slight differences in magnitude. Thus, it can be deduced that categorizing the mines into three categories of fully implemented and optimized, fully implemented, and partially implemented holds credibility and robustness findings based on triangulation this approach (Patton, 2015).

OSH Compliance

The descriptive analysis of variables included in the analysis in terms of frequences, means score, and stochastic dominance tests. The results are presented as: -

Table 3.4: Overall OSH Compliance

OSH Compliance Indicator	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total
Procedure Adherence	34 (5.8%)	159 (27.1%)	220 (37.5%)	136 (23.2%)	37 (6.3%)	586 (100.0%)
Incident Reporting Frequency	30 (5.1%)	166 (28.3%)	218 (37.2%)	139 (23.7%)	33 (5.6%)	586 (100.0%)
Training Completion	35 (6%)	161 (27.5%)	196 (33.4%)	163 (27.8%)	31 (5.3%)	586 (100.0%)
Safety Audit Score	35 (6%)	158 (27%)	212 (36.2%)	138 (23.5%)	43 (7.3%)	586 (100.0%)
Hazard Identification Rate	39 (6.7%)	155 (26.5%)	198 (33.8%)	168 (28.7%)	26 (4.4%)	586 (100.0%)
Timely Hazard Reporting	25 (4.3%)	155 (26.5%)	236 (40.3%)	138 (23.5%)	32 (5.5%)	586 (100.0%)

Source: Survey Data, 2025

The results in Table u show that majority of responses across all six indicators of OSH compliance were neutral [33.4 – 40.3%], followed by disagree [26.5 – 28.3%]. The results indicate that in overall there was a relatively no consistent procedure adherence, not high incident reporting frequency, lack of training completion, not high safety audit score, not high hazard identification rate, and less timely hazard reporting. However,

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DOI: https://dx.doi.org/10.64839/sjsi.v5i8.5
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about a quota agree [23.2 – 28.7%], indicating that some of the workers realize anticipated OSH requisites. To be able to determine OSH compliance levels across major mines the Composite scores are presented in Table 3.5.

Table 3.5: OSH Compliance Scores

Major Mine	N	Min	Max	Mean	SD	Median	IQR
Bulyanhulu Gold Mine	98	3	4.67	3.85034	0.33887	3.83	0.5
Geita Gold Mine	97	3	4.5	3.79038	0.31113	3.83	0.33
Buckreef Gold Mine	99	2.33	3.67	3.03367	0.3299	3	0.33
New Luika Gold Mine	98	1.33	3	2.12075	0.29966	2.17	0.5
Ngaka Coal Mine	96	1.5	2.83	2.10069	0.28662	2	0.38
Overall	**586**	**1.33**	**4.67**	**2.98188**	**0.76127**	**3**	**1.33**

Raw Data - not normaly distributed [Shapiro-Wilk Statistic = 0.96579, p-value <0.001]
Log Transformed Data – not normaly distributed [Shapiro-Wilk Statistic = 0.95527, p-value<0.05]

Source: Administrative Data, 2025

The results in Table 3.5 show that the composite score of OSH compliance was not confirmed to follow normal distribution. Thus, the median score is used to compare OSH compliance across major mines. The results show that relatively higher median scores are associated with major mines with high digital implementation maturity such as Bulyanhulu Gold Mine (3.83), and Geita Gold Mine (3.83), while lower median scores are happened to be for major mines with lower implementation maturity such as Luika Gold Mine (2.17) and Ngaka Coala Mine (2). Similar trends are evident for the means scores despite lacking statistical consistency given non normal distribution. The level of variation and how this variation is associated with the digital tools implementation level is further analysed using the Stochastic Dominance Test. The results are presented in Figure 3.3.

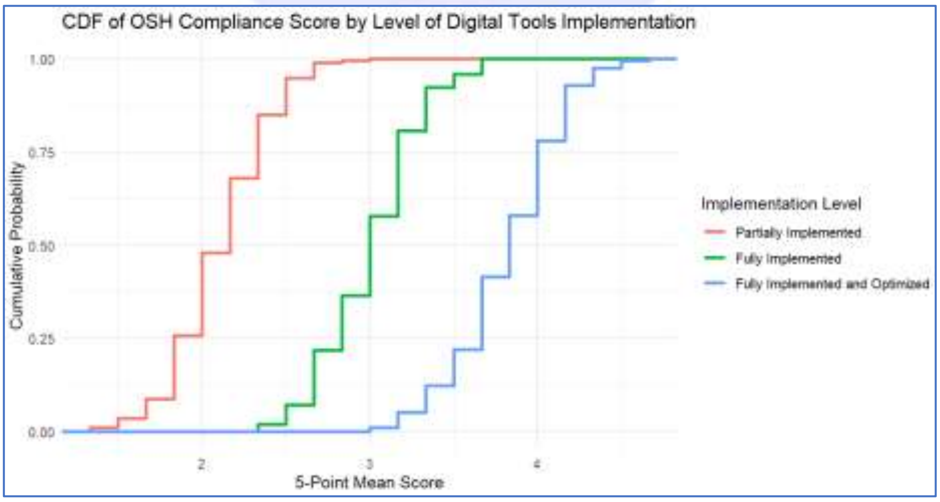

Figure 3.3: Stochastic Dominance Test for OSH Compliance
Source: Survey Data, 2025

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Exploratory analysis results in Figure j show there was a first order stochastic dominance of OSH compliance score by major mines with fully implemented and optimized digital tools compared to major mines with fully implemented level [KS Test: D = 0.80078, p-value < 0.001] and partially implemented level [KS Test: D = 0.99485, p-value < 0.001]. Similarly, there was a first order stochastic dominance of OSH compliance score by major mines with fully implemented digital tools compared to those with partially implemented level [KS Test: D = 0.87739, p-value < 0.001]. The findings predict unambiguously the positive impact of implementation of digital tools on OSH compliance as was further established in the predictive model regression analysis.

These findings align with assessment from secondary sources including interna and external audit reports. The five indicators used include OSH Compliance Certificate, Training Participation, Worker Involvement & OSH Committee, and OSH Audit. The summary of findings with respect to these indicators is presented in Table 3.6.

Table 3.6: Documented Scores on OSH Compliance Indicators

	OSH Compliance Indicators					
Major Mine	OSH Compliance Certificate	Training Participation	Worker Involvement & OSH Committee	OSH Audit	Overall Average	Implementation Status
Geita Gold Mine	100%	30%	80%	95%	76%	Fully implemented & optimized
Bulyanhulu Gold Mine	100%	20%	80%	95%	74%	Fully implemented & optimized
Williamson Diamond Mine	100%	5%	60%	80%	61%	Fully implemented
Buckreef Gold Mine	100%	5%	60%	80%	61%	Fully implemented
New Luika Gold Mine	100%	5%	50%	70%	56%	Partially implemented
Ngaka Coal Mine	100%	5%	45%	60%	53%	Partially implemented

Source: Administrative Data, 2025

The results in Table 3.6 show that, on average the major mines with high scores of 76% or 74% happen to be those with fully implemented and optimized digital tools, followed by those with fully implemented with scores of 61% each. On the other hand, the major mines with least average scores of 56% or 53% are those with partially implemented digital tools. However, all major mines had received OSH Compliance Certificate of 100% score on compliance with the minimum requirements as stipulated in the OSH guidelines. This finding indicates that in the lens of minimum requirements for OSH compliance there is no variability between the mines included in the study. Based on this finding there are at least two main implications for this study. The first implication is that OSH compliance levels are approaching to the saturation point beyond which there cannot be a guarantee for meaningful incremental realizations under the prevailing preconditions, all else being equal. This is in agreement with the axiom of organizational theory referred to as the institutional isomorphism which is common for organizations in the same field as they exhibit maximum compliance due to regulatory pressure, or industry standards (DiMaggio & Powell, 1983, as cited in Greenwood et al., 2017). The second implication is that further improvements in OSH compliance scores might highly depend on out of box options such as the adoption of digital tools among others. This finding aligns with Kim et al. (2021) as they found that optional innovations that are not necessarily mandated improve OSH. Another study found that safety technologies are main differentiators beyond the standard operating requisites (Zhou et

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al., 2022). These findings help to explain the underlying near zero random effects between the major mines that are included in this study as discussed in next subsections of this report.

Multivariate Regression Analysis

Exploratory analysis of the dependent variable was performed to ensure choosing the best model. The exploratory analyses result how that the dependent variable was characterized with non-normal distribution [Shapiro-Wilk Statistic = 0.96579, p-value <0.001], common log transformations failed to normalise the distribution [Shapiro-Wilk Statistic = 0.95527, p-value], and Likert scale with imaginary bounds of 1-5 since the realizations of this variable emerged from mean score of 1-5 Likert scale involving 5 indicators. The next option was to rescale the dependent variable from 1-5 into 0-1 bounds to suffice the assumptions for using beta regression.

Choice Between Random Effects Vs No Random Effects Model

The context of data analysis using regression approach was subject to challenges associated with having nested data levels with only six companies and 586 staff-level data. There was a problem of capturing company level fixed effects, where company dummies ended up with identity matrix, and also the company level covariates such as ownership and mineral type suffered the aliased coefficients problem. A stepwise selection of covariates was guided by the diagnostic tests for multicollinearity as shown in Table 3.7.

Table 3.7: Multicollinearity

	Model 1	**Model 2**	**Model 3**
Predictor	VIF	GVIF^(1/(2*Df))	GVIF^(1/(2*Df))
fully_dummy	2.71	1.63	1.38
optimized_dummy	52.19	2.11	2.09
efftrain_dmmy4	1.06	1.03	1.03
Efftrain_dmmy5	1.06	1.03	1.03
usage_score	2.46	1.57	1.57
w_experience	1.05	1.01	1.01
size_emply	28.32	removed	1.41
mine_type	58.68	1.42	removed
Owenership	removed	removed	removed
Mineral	removed	removed	removed

*Threshold: VIF< 10, or GVIF^(1/(2*Df)) < 2.2*

Multicollinearity test results after excluding ownership and mineral type show that either mine type (GVIF^(1/(2*Df)) = 1.42) or mine size by number of employees (VIF^(1/(2*Df)) = 1.41) are equally statistically feasible, both with GVIF^(1/(2*Df)) < 2.2. However, mine type is in favor as may distinguish needs for digital tools implementation given the varying risk levels associated with underground as opposed to open pit. Nonetheless, given the mines are already from the 'major mines' category that may have less meaningful differences in terms of scale (International Council on Mining and Metals [ICMM], 2019; World Bank, 2020).

Before finalizing on the final model, the random effects model was tested to ensure possibility of extending robustness. The results show that the random-effects beta regression model had near zero effects (grouping factor = company, Estimated Standard Deviation = 0.000137). The results imply very negligible variation at company level. Details are shown in Table 3.8.

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SJSI 2025, Volume 5, Issue 8, Page 78-92
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ISSN: 2676-2714
DOI: https://dx.doi.org/10.64839/sjsi.v5i8.5
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Table 3.8: Random Effects at company level vs with No Random Effects

Metric	No Random Effects	With Random Effect (company)
AIC	-1182.07	-1180.07
BIC	-1133.96	-1127.59
logLik	602.03	602.03
Number of observations	586	586

The results in Table 3.8 show AIC, BIC and LogLik are strongly identical for the two models. Thus, the model with no random effects was preferred in line with (Bell et al., 2019; McNeish & Stapleton, 2016).

Beta Regression Analysis with No Random Effects

The first model that was fitted revealed there was extreme negative deviations of -7.3 from the residuals despite having mean close to zero [0.014] as required. The results suggested a weighted beta regression was necessary to ensure robustness. The third model was therefore the best fit. The summary statistics are presented in Table 3.9 below: -

Table 3.9: Model Summary Statistics

	Deviance Residuals (Lower is better)			**Pearson Residuals (Lower is better)**			
Model	Min	Max	Mean	Max	Mean	**Phi**	**Pseudo R^2**
Model 1	-7.3	3.18	0.014	2.41	0.02	34.16	0.783
Model 2 (Weighted)	-4.83	3.1	0.013	2.8	**0.018**	**100.98**	**0.942**

Thus, the final model was the best fit, mainly because of reliance on bootstrapped standard errors and the use of a weighted regression. Bootstrapping the standard errors was useful to enhance robustness given the limitations from few company level covariates necessitated by the small number of major mines (Wooldridge, 2010; Wang & Li, (2020). The final results are shown in Table 3.10 together with the visualizations in Figure 3.4.

Table 3.10: Weighted Beta Regression Results

Predictors	**AME**	**Std. Error^b**	**Z-Statistic**	**P-Value**	**95% C. Interval**	
Fully vs partially***	0.1770	0.004478	39.534	<0.0001	0.1682	0.186
Optimized vs Partially***	0.3336	0.005239	63.67	<0.0001	0.3233	0.3438
Digital Tools Usage***	0.1487	0.0039	38.127	<0.0001	0.1410	0.1563
Mixed vs Open pit	-0.0022	0.005137	-0.426	0.66993	-0.01226	0.0079
Underground vs Open pit**	0.0181	0.00718	2.521	0.0117	0.0040	0.0322
Highly trained	0.0005	0.00382	0.1322	0.89485	-0.00698	0.008
Very highly trained***	0.0175	0.00309	5.6589	<0.0001	0.0114	0.0235

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ISSN: 2676-2714
DOI: https://dx.doi.org/10.64839/sjsi.v5i8.5
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Exp: 4-7 yrs vs below 4 yrs***	0.0167	0.00367	4.547	<0.0001	0.0095	0.0238
Exp: 8+ yrs vs below 4 yrs**	0.0087	0.00334	2.612	0.00899	0.0022	0.0153

Significant at 5% level of significance, * Significant at 1% level of significance, AME – Average Marginal Effects, [b]Bootstrapped Standard Errors

Based on the results in Table 3.10 the researcher was able to conclude on the research hypotheses as shown in Table 3.11.

Table 3.11: Conclusion on Hypothesis

Hypothesi	**Condition**	**Conclusion**
H1: Digital tools implementation positively affects OSH compliance in mining operations	P-value<0.05	Accepted
H2: The relationship between digital tools implementation and OSH compliance is mediated by level of digital tools usage	P-value<0.05	Accepted
H3: Training effectiveness moderates the relationship between digital tools and safety performance	P-value<0.05	Accepted

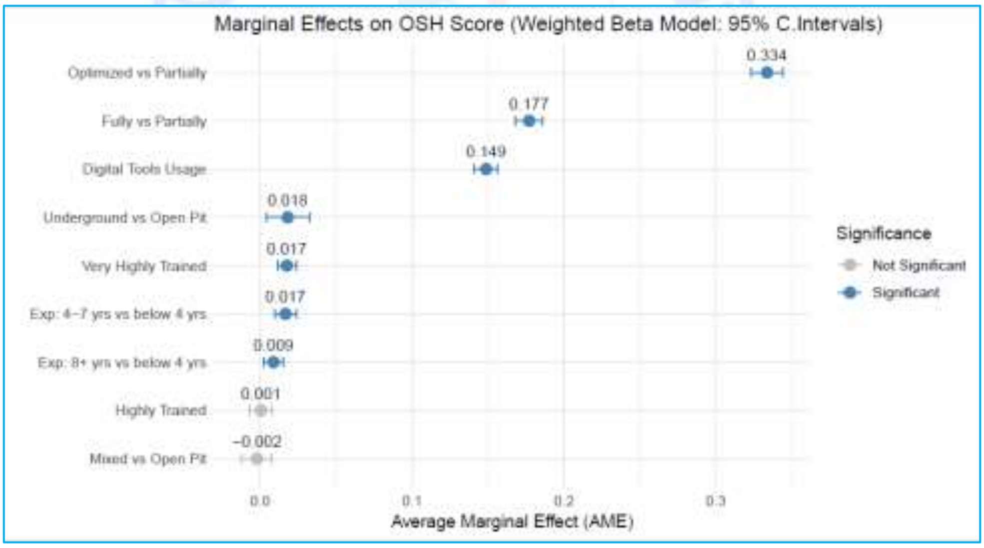

Figure 3.4: Visualization of the Marginal Effects
Source: Survey Data, 2025

Implementation of Digital Tools and OSH Compliance

The results in Figure 3.4 show that big mines with fully implemented and optimized digital tools exhibit higher OSH compliance levels by 33.4% compared to the mines with partially implemented digital tools [Marginal Effects = 0.3336, p-value<0.001; 95% CI = 0.323 - 0.344]. Also, the mines with fully implemented digital tools had 17.7% increase in OSH compliance levels compared to mines with partially implemented digital tools [Marginal Effects = 0.177, p-value<0.001; 95% CI = 0.168 - 0.1858]. The results show very tight confidence intervals implying consistency. The study concludes that implementation of digital tools has positive significant impact on OSH compliance with effect ranging from 17.7% to 33.4% for every unit increase in implementation level. the finding indicates that OSH digitalization is a triggering factor towards OSH compliance

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ISSN: 2676-2714
DOI: https://dx.doi.org/10.64839/sjsi.v5i8.5
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by supporting safety behaviors, promptness of interventions, and automation, hence improved safety monitoring and control.

Digital Tools Usage and OSH Compliance

The results in Figure 3.4 show that big mines a unit increase in usage of the digital tools is associated with an increase in OSH compliance levels by 14.9% [Marginal Effects = 0.149, p-value<0.001; 95% CI = 0.141 - 0.156]. The results indicate a positive significant effect of digital tools usage on OSH compliance.

Training and OSH Compliance

The results in Figure 3.4 show that big staff who received very highly effective training had 1.8% OSH compliance likelihood compared to those with lower levels of training [Marginal Effects = 0.0175, p-value<0.001; 95% CI = 0.0114 - 0.0235]. An infinitesimal incremental impact of training on OSH compliance score need not to be overlooked since the baseline group was already having high median predicted probability of 50.9% [IQR = 0.239 – 0.729]. As a result, the incremental gain from additional training is inevitably smaller because there is less opportunity for significant gains because the baseline performance is already close to a good level.

Figure 3.5: Predicted OSH score by Training effectiveness

Source: Survey Data, 2025

4.2 Discussion

This study found that improvements in OSH compliance scores might highly depend on out of box options such as the adoption of digital tools among others. This finding aligns with Kim et al. (2021) as they found that optional innovations that are not necessarily mandated improve OSH. Another study found that safety technologies are main differentiators beyond the standard operating requisites (Zhou et al., 2022). These findings help to explain the underlying near zero random effects between the major mines that are included in this study as discussed in next subsections of this report.

The study found that implementation of digital tools has positive significant impact on OSH compliance with effect ranging from 17.7% to 33.4% for every unit increase in implementation level. the finding indicates that OSH digitalization is a triggering factor towards OSH compliance by supporting safety behaviors, promptness of interventions, and automation, hence improved safety monitoring and control. The findings align with Saif et al. (2024) who found that smart safety systems demonstrated enhanced proactive safety control and compliance procedures by enabling real-time hazard detection and automatic alerts. Also, the findings are supported by Legierski et al. (2023), as they found that real-time digital monitoring systems had improved personal protective equipment (PPE) compliance. Unlike previous studies which were focusing on construction sector, the findings in this study focus on mining sector which is of unique context.

On the other hand, a study by Bapela (2024) found that wearable technology can improve safety by proactively preventing incidences, by enhancing information flow and delivering real-time hazard notifications. Although Bapela (2024) focused on hazard alerts per se, the findings highlight the mechanism through which a broader implementation of digital tools,

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ISSN: 2676-2714
DOI: https://dx.doi.org/10.64839/sjsi.v5i8.5
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which is the focus of this study, may have mediated its impact on OSH compliance. Furthermore, the potential of digital OSH is far reaching and may require more of optimization of all associated subsystems as deemed by the Socio-Technical Systems theory. According to sociotechnical theory, digital systems only increase compliance when technical solutions are well integrated to properly align organizational procedures, worker participation, and social structures (Fowler & Nørbjerg, 2023).

Also, the findings indicate a positive significant effect of digital tools usage on OSH compliance. This implies that overall performance of OSH compliance initiatives through digital tools depends not only on implementation but also on the level of usage and certainly the proper usage of these tools. The finding implies that use of digital tools results in improved adherence to safety protocols, increased incident reporting frequency, high safety audit score, hazard identification rate, and timely hazard reporting (Imam et al., 2024; Kartik & Manimaran, 2023).

Also, the study findings imply that employees and managers across sections and departments of major mines have positive consideration of digital devices as a function of their perceived usefulness and ease of use of safety digital tools. this is mainly due to the strong axiom of the TAM stating that users are more likely to use digital regularly when they feel that they make their safety-related tasks easier and more efficient (Venkatesh & Davis, 2000; Pal et al., 2023).

Furthermore, the findings imply that the digital transformation for OSH is actively integrated into safety workflows, enhancing procedures like hazard detection, incident reporting, and protocol adherence. This finding is in line with the sociotechnical theory axiom that such a realization is possible when the technology subsystem is well integrated with the socio context of the working environment (Waterson, 2020; Carayon et al., 2021).

On the other hand, the study findings indicate that although there was infinitesimal incremental impact of training on OSH compliance score need not to be overlooked since the baseline group was already having high median predicted probability of 50.9% [IQR = 0.239 – 0.729]. As a result, the incremental gain from additional training is inevitably smaller because there is less opportunity for significant gains because the baseline performance is already close to a good level. The findings imply that in order to give workers the information and abilities they need to identify, prevent, and address workplace hazards, occupational safety and health (OSH) training is essential. Good training cultivates hazard reporting, lowers incident rates, and improves adherence to safety procedures, especially when aided by digital tools (Fatima et al., 2022).

Moreover, frequent and engaging safety training helps employees better incorporate safety practices into their everyday routines and promotes a proactive safety culture. Based on the socio-technical systems, training is a crucial instrument for coordinating technological interventions with a system's human component, guaranteeing that digital OSH tools are not only embraced but also utilized efficiently (Carayon et al., 2021). Comparably, training affects perceived usefulness and ease of use, increasing technology acceptance, which in turn improves safety behavior and compliance, according to the Technology Acceptance Model (TAM) (Venkatesh & Davis, 2000).

5.0 CONCLUSION

The study found that implemented digital tools had a positive significant impact on OSH compliance with a minimum marginal effect of 17.7% [AME = 0.177, p-value<0.001; 95% CI = 0.168 - 0.1858], and a maximum marginal effect of 33.4% [AME = 0.3336, p-value<0.001; 95% CI = 0.323 - 0.344]. Other factors that affect OSH compliance include but are not limited to training effectiveness [AME = 0.0175, p-value<0.001; 95% CI = 0.0114 - 0.0235], and the usage of digital tools [AME = 0.149, p-value<0.001; 95% CI = 0.141 - 0.156].

Thus, the study consludes that the impact of implemnation of digital tools on OSH complaince is substantially explained by the strong axioms of the sociotechnical systems theory and the technological acceptance model. The axioms requires that both the technical subsystems and the organizational systems need to be optmally amalgamated for effective implemnation of safety digital tools. However, having the tools implemented requires that they are being used as anticipated and that depends on their perceived usefulness, and ease of use.

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ISSN: 2676-2714
DOI: https://dx.doi.org/10.64839/sjsi.v5i8.5
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This study is uniquely deviating from previous studies and focused on the impact of digital transformation on OSH compliance in the context of the mining sector in developing country. The study gains its weight in the country like Tanzania where occupational risks in mining sector are a major concern coupled with paucity of empirical evidence regarding the way forward. The study findings extend the knowledge frontier to the understanding of extent to which digital tools can greatly improve OSH compliance especially when they are effectively implemented with a more holistic approach.

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