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Implementation of the Fourth Industrial Revolution Technologies in Tanzania's Downstream Oil and Gas Industries

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Implementation of the Fourth Industrial Revolution 4.0 Technologies in Tanzania's Downstream Oil and Gas Industries

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ABSTRACT

The advent of the fourth industrial revolution (IR4.0) has resulted in the digital transformation of multiple sectors of the economy due to the disruptive nature of the technologies driving the revolution. The technologies have already found their way into the oil and gas industries across the globe, especially in upstream, midstream, and downstream operations. However, the degree of implementation is not the same for these operations, considering the complexities involved, integrated process, the associated risk and investment cost, among others. This study aimed to establish the implementation level of IR4.0 technologies in the downstream operations. A survey method was employed to collect information regarding their implementation. SPSS 21 and SmartPLS 4.1.0.9 software were used in the data analysis. Results indicated that industrial internet of things (IIoT) or IoT is the most influential technology on both refining, storage, transportation and distribution processes with mean values of 4.93, 4.73, 4.17 and 4.64, respectively. It was also found that IIoT/IoT, simulation, and cybersecurity technologies have the highest implementation level in Tanzania's oil and gas industries, with levels of 3.4, 3.3, and 3.0, respectively. The result indicated that oil and gas industries in Tanzania are not adequately implementing these technologies, as they are at the medium level, necessitating more effort on their integration into downstream oil and gas operations to reach the highest level of their implementation. The study proposed strategies for implementing IR4.0 technologies in downstream operations, highlighting the establishment of core concepts through IoT and cloud computing as the top strategy. Smart pipeline monitoring ranked second, while agile regulatory frameworks were the lowest. Other strategies include cloud-based data management, workforce skill upskilling, and strengthening cybersecurity. The government is urged to create a supportive legal environment to boost the fourth IR innovation in the sector.

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Highlights

- The fourth industrial revolution (IR4.0) is driving digital transformation across various economic sectors, notably in the oil and gas industry.
- Implementation of IR4.0 technologies varies among upstream, midstream, and downstream operations due to complexities, risks, and costs.
- A study surveyed the implementation level of IR4.0 technologies, specifically in downstream operations
- The industrial internet of things (IIoT) emerged as the most influential technology, with mean implementation values of 4.93 for refining, 4.73 for storage, 4.17 for transportation, and 4.64 for distribution.
- IIoT/IoT, simulation, and cybersecurity technologies had the highest implementation levels in Tanzania's oil and gas industry, scoring 3.4, 3.3, and 3.0, respectively.
- The overall implementation of these technologies is at a medium level, indicating a need for enhanced integration in downstream oil and gas operations.

INTRODUCTION

The advent of the fourth industrial revolution (IR4.0) since 2011 resulted in the digital transformation of multiple industrial sectors due to the disruptive nature of the driving technologies (Khan et al., 2024). The technologies such as Internet of Things (IoT), artificail intelligence (AI), cybersecurity, big data analytics (BDA), cloud computing, and 3D printing have already found their ways in multiple sectors, including manufacturing industries, pharmaceutical industries, food industries, retail industries, oil and gas industry, among others (Islam et al., 2025). Technologies such as IoT and Cyber-physical systems have proven to influence human factors in the oil and gas refinery industry (Restuputri, 2024). Big data

analysis, AI, machine learning (ML) and cloud computing technologies also enabled the management, storage and processing of large amounts of data in the oil and gas industry. This is witnessed by the generation, storage and processing of a large amount of pipeline data (1.5TB/600km) and plant operation data (8GB/year) through big data analytics, AI, ML and cloud computing as stipulated by (Majstorović, 2022). Exchange of information, improved safety, location of oil and gas leakage, predictive maintenance, and real-time plant operation monitoring are also enabled by the employment of IoT, cybersecurity, machine learning, and AI technologies in the oil and gas industry (Majstorović, 2022; Sharma et al., 2024). Moreover, virtual reality, especially the employment of digital twin (DT) technology, enabled process optimisation, failure prediction, operation monitoring, drilling simulation, real-time modelling, hydraulic and temperature simulation in the oil and gas industry (Belo et al., 2025). It is also noted that DT in the oil and gas industries not only enable the organisation to adopt the technology but also to foresee and anticipate the future in the field. Employment of DT enable organisation to improve operational efficiency, knowledge sharing among the employees, guarantee employee safety, real-time data analysis and the integration of virtual reality in the operation (Benito et al., 2024).

It should also be noted that operations in the oil and gas industry are divided into three, namely upstream, midstream and downstream operations. While the upstream entails the exploration and drilling, midstream entails the transportation and downstream concerns with refining and selling of oil and gas products (Belo et al., 2025). The integration of IR4.0 technologies in the oil and gas industry is uneven, taking into account the three different operations as described above. The extent to which the technologies are integrated in the upstream operations is different from midstream and downstream, mainly due to the complexities of the operations, the deployed machines, methods and techniques while undertaking the operations (Majstorović, 2022). Specifically, IR4.0 continues to impact the downstream operations through the employment of AI and machine learning technologies. The technologies are currently used in automatic online optimisers which are directly connected to information systems for real-time data collection in the entire refinery plant, enabling the organisation to make an informed operation decision and planning (Unzueta et al., 2022). The extensive heat in the oil and gas refinery industries has also resulted in the deployment of residual heat to power the ATEX-certified industrial IoT devices, replacing the conventional batteries and their associated maintenance cost (Aragonés & Oliver, 2025). The technology enabled the industry in condition monitoring during the operations and predictive maintenance of machinery parts, eventually lowering the operation cost and increasing the output.

Nevertheless, the employment of preventive and reactive maintenance in the refinery industry is currently being replaced by the use of long short-term memory (LSTM) autoencoder, a machine learning model to detect anomalies and predicting the failure, which enables predictive maintenance (Thaker & West, 2024). Technologies such as AI, IoT, augmented reality, autonomous robots, additive manufacturing and cloud computing have proven their potential in monitoring leakage in the pipeline during transportation (Taifa et al., 2025). Pipeline maintenance and inspection during transportation is enabled by the employment of IR4.0 technologies, including robots and an intelligent control system (Xu et al., 2025). Metering system in the oil and gas industry in the downstream operations is also enabled by IR4.0 technologies. This is justified by the employment of a data-driven multiphase virtual flowmeter (DD-MVFM) using ML technology, which enhanced the estimation of flow rate, prediction of future production and real-time monitoring (Farag & Aly, 2024). The integration of IoT technology has also enabled remote meter reading and real-time monitoring through a smart flow computer (Kilang et al., 2025). The innovation has enabled real-time data acquisition, improved efficiency in operations, as well as precision in measurement specially by integrating IoT and microcontrollers.

Generally, the integration of IR4.0 technologies in the oil and gas industries is not even when viewed at three different operations, such as upstream, midstream and downstream. A study conducted by Al-hajri et al. (2024) asserts that the IR4.0 technologies are mostly integrated in the upstream operations, mainly due to the associated operation risk, high investment cost and impact it has on the revenue. Downstream, on the other hand, is the least when it comes to integrating the technologies in various operations, mainly due to the associated complexities during operations (Thaker & West, 2024; Al-hajri et al., 2024). However, the integration of IR4.0 technologies in the downstream operations is substantial for the companies to increase operational efficiency, increase transparency during custody transfer at several points, and improve health and safety during operations, as pointed out by Unzueta et al. (2022). Based on various activities undertaken in the downstream operations such as refining, storage, transportation and distribution of oil and gas, this study aimed to illuminate the implementation of IR4.0 technologies in the downstream operations in Tanzania's oil and gas industries. The study was guided by the following research questions enabling the attainment of the main objection.

RQ1. What are the influential IR4.0 technologies in the oil and gas industry in Tanzania?
RQ2. What is the IR4.0 technologies' implementation level in the oil and gas industries in Tanzania?
RQ3. What are the strategies to integrate IR4.0 technologies in the oil and gas industry in Tanzania?

The remaining sections of this study are organised in the following sequence. Section 2 describes the methodology used in response to the posed research questions in the Oil and Gas industry. Section 3 presents the results and findings from the survey regarding the influential technologies, implementation level and the strategies. Section 3 also presents a discussion corresponding to the results and findings observed in line with the research questions. Likewise, Section 4 covers the concluding remarks, which cover the study's recommendations and the future research.

METHODS AND MATERIALS

Research Design

Quantitative research design was used to accomplish the research objectives. Three regions were involved in this study, which include Dar es Salaam, Lindi and Mtwara regions. These regions were selected due to the presence of downstream activities including refining, storage, transportation and selling of bulk quantities of oil and gas products. More specifically, Dar es Salaam was selected considering the importation of oil through Dar es Salaam port; Lindi and Mtwara were selected because of the presence of a gas processing plant. A closed-ended questionnaire examined the most notable technologies of the fourth industrial revolution (IR4.0), barriers and implementational strategies of IR4.0 technologies in the oil and gas sector, and potential strategies for effective integration. The referenced works included Schumacher et al. (2019), Steinlechner et al. (2023) and Taifa et al. (2025), to create the questionnaire as they were among the few scholars to discuss IR4.0 technologies in manufacturing and the oil and gas sector. The downstream oil and gas sector model created by Schumacher et al. (2016) was used to assess the level of IR4.0 technology adoption. The survey implemented a 5-point Likert scale to measure the level of adoption of the IR4.0 technologies within the downstream oil and gas sector.

Sample Design and Unit of Analysis

The study employed a non-probability purposive sampling technique to collect data from various oil and gas industries, specifically in the downstream operations. The technique was chosen following its simplicity in sample identification, lower cost and time saving during the process as denoted by Maganga & Taifa (2023). Individuals working in the downstream oil and gas operations were the unit of analysis, in which their selection was based on the level of experience, education level and position held in the organisation. Process engineers, supervisors and managers with the experience of more than years of experience in the downstream oil and gas operations were the subject of this study.
Sample size was computed using Equation (1) developed by Taherdoost as described by Maganga & Taifa (2024).

$$n = \frac{p \times (1-p) \times Z^2}{e^2} \quad (1)$$

whereby n is the sample size required in the study, p is the recurrence of a state, e is the percentage error tolerance, and Z is the confidence level. With the recurrence of a state (p) value of 7%, confidence level of 95% (Z=1.96) and error tolerance of 5%, the sample size of 100 was obtained. Therefore, a total of 100 individual which include process engineers, supervisors, and managers working in the oil and gas industries, specifically in the downstream operations, were involved in this study.

Data Collection Method

Data were collected using a closed-ended questionnaire, making it possible for respondents to rate various aspects regarding the implementation of IR4.0 technologies, the influential technologies and strategies for IR4.0 integration. The strategies for effective integration of IR4.0 technologies in the downstream oil and gas industry operation were obtained from the literature review, which were then included in the questionnaire for respondents to indicate how they agree on the effectiveness of each strategy.

Data analysis

The collected data were first edited and cleaned to ensure free error during the analysis of the findings. After cleaning the data, descriptive analysis was conducted using SPSS 21 regarding the level of experience, leadership position, and the level of education possessed by the respondents. SPSS 21 software was chosen because it offers a wide range of analysis and has been used effectively in quantitative research (Jakobo & Taifa, 2025). The descriptive analysis was followed by the confirmatory factor analysis (CFA), measurement and structural model analysis of the variables for establishing the implementation level of IR4.0 technologies in the oil and gas downstream operations using partial least squares structural equation modelling (PLS-SEM). The PLS-SEM analysis was conducted by using SmartPLS 4.1.0.9 software due to its effectiveness, composition and accuracy in the results from the survey.

The CFA was performed using factor loading with the values > 0.7, in which factors with < 0.7 loading were rejected for further analysis, as pointed out by Guo & Erdenebold (2025). Factors with >0.7 loadings were retained for measurement and structural model analysis, in which the reliability and validity of the factors were assessed. For measurement model analysis, Cronbach's Alpha value, composite reliability and reliability coefficient were used for internal consistency check with a threshold of > 0.7, while average variance extracted with a threshold of >0.5 was used for convergent validity check (Subhaktiyasa, 2024). The discriminant validity of the model was assessed using Fornell-Larcker criteria based on the diagonal element. Path significance ($p<0.05$), coefficient of determination ($R^2 > 0.5$) and predictive relevancy ($Q^2>0$) were used to analyse the structural model (Rasoolimanesh, 2022).

IR4.0 Implementation Level in the Downstream Oil and Gas Industry's Operations

The measurement and structural model analysis of the various factors enabled the assessment of their reliability and validity in establishing the implementation level of IR4.0 technologies in oil and gas downstream operations. The IR4.0 technologies implementation level in the downstream operations was established using the model developed by Schumacher et al. (2016) as presented in Equation (2).

$$M_D = \frac{\sum_{i=1}^{n} M_{DIi} x g_{DIi}}{\sum_{i=1}^{n} g_{DIi}} \quad (2)$$

whereby: *M*-implementation, *D*-dimension, *g*-weights of indicator, *I*-item, *n*-number of measurement items.

Strategy Development and Validation

A structured questionnaire was developed and administered to a sample of 100 professionals, including process engineers, supervisors, and managers, from the oil and gas sector, downstream operations, in order to rank the potential strategies. Subsequently, the validation of strategies was conducted through a focus group discussion with 11 professionals in the oil and gas sector. The strategies were chosen and validated based on previous studies such as Nyumba et al. (2018), Jung & Ro (2019), and Robert et al. (2023). Of the eleven industry experts consulted, six had over 10 years of experience working with the oil and gas industry, and the other five had between 5 and 10 years of experience.

RESULTS AND DISCUSSION

Reliability Testing, Response Rate and Demographic Information

A reliability test was conducted to ascertain whether the data collected would render the correct information from the survey. Cronbach's Alpha was considered the main criterion for a reliability test, in which the value should not be less than 0.7 (Jakobo & Taifa, 2025). The collected data were tested using SPSS 21, and the value of Cronbach's Alpha was 0.97, indicating that the data were reliable. A total of 110 questionnaires were distributed, and 100 questionnaires were returned, demonstrating that the response rate was 100% for the 100-sample size of the study. Moreover, demographic information of the respondents, including job title, working experience and level of education are presented in Table 1.

The demographic information indicates that 90% of the respondents have at least three years of working experience in the downstream oil and gas operation. This demonstrates the reliability of the information provided by the respondents, considering their work experience in oil and gas downstream operations. About 80% of the respondents were university graduates, while 15% possessed a diploma and 5% master's degree, indicating that the respondents are knowledgeable, signifying the reliability of the findings. Moreover, 32% of the respondents were process engineers while 28% were instrumentation engineers, demonstrating that the respondents are directly involved in the downstream oil and gas operations.

IR4.0 Influential Technologies in the Oil and Gas Industries

Respondents were asked to rate the most influential IR4.0 technologies in the downstream oil and gas operations based on the critical operations involved in the downstream operations. The involved critical activities in the downstream oil and gas operations include refining, storage, transportation, and distribution (Unzueta et al., 2022). The IR4.0 influential technologies on each of the downstream oil and gas operations are presented in Table 2 along with their mean and standard deviation. The influential ranking was based on the 5-point Likert scale, where 5 indicates strongly agree, and 1 indicates strongly disagree in downstream operations.

Table 1. Demographic Information of the Respondents

Demographic Items	Respondents	Percentage (%)
Working Experience		
Less than 3 Years	3	0.01
Between 3 and 5 Years	51	0.51
Between 6 and 10 Years	40	0.40
More than 10 Years	6	0.08

Highest Level of Education Achieved		
Ordinary Secondary School	-	-
High School/Diploma/FTC	15	0.15
Undergraduate	80	0.80
Masters	5	0.05
PhD	-	-
Job Title		
Process Engineer/Technician	32	0.32
Instrumentation Engineer/Technician	28	0.28
Metrologist	14	0.14
Logistic Manager	14	0.14
Marketing Manager	12	0.12

Table 2. IR4.0 Influential Technologies in the Downstream Oil and Gas Operations

Downstream Operation	IR4.0 Influential Technologies	Mean	Standard Deviation
Refining	Industrial and /IoT	4.93	0.29
	Artificial Intelligence	4.64	1.07
	Digital Twin	4.57	0.52
	Big data analytics	3.97	0.50
	Cyber-physical system	3.75	1.14
	Autonomous robots	3.46	0.87
Storage	Industrial and/IoT	4.86	0.37
	Digital Twin	4.73	0.47
	Autonomous robots	4.64	0.50
	Mobile technology	4.00	0.87
	Cyber security	3.20	1.76
	Artificial intelligence	2.90	1.24
	Simulation	2.86	0.97
Transportation	Industrial and/ IoT	4.70	0.46
	Mobile Technology	4.66	0.72
	Cloud computing	4.58	0.61
	Digital twin	4.11	0.87
	Artificial intelligence	3.25	1.71
	Drones	3.13	1.31
Distribution	Industrial and /IoT	4.64	0.75
	Machine learning	4.49	0.84
	Cyber security	4.32	1.02
	Autonomous systems	3.43	1.70
	Big data analytics	3.25	1.21

The data presented in Table 2 demonstrates the effect of IR4.0 technologies on the key downstream activities of the oil and gas sectors. For the downstream refining processes, the results show that IIoT is the most impactful technology, with respondents indicating this, giving a mean value of 4.93, which shows a high consensus on the significance of IIoT in the downstream oil and gas operations. This is also evident in, Wanasinghe et al. (2020), who specifically mentioned that with IIoT, organisations would experience optimised output, operational efficiency, predictive maintenance, and improved safety in the working environment. Conversely, due to limited operational scope in the refining processes, downstream operations did not appear to be significantly influenced by then refining processes.

IIoT had the greatest importance to the oil and gas storage operations with a mean value of 4.73. This shows the respondents marked 4 or 5 and therefore agree with the importance of IIoT in the oil and gas storage operations. As mentioned by Khan et al. (2024), the use of IIoT in oil and gas storage is necessary because of the operational risks and it helps the organization avoid losses and increase operational safety. Regarding oil and gas transportation, IIoT also had the greatest importance as an IR 4.0 technology with a mean value of 4.17, while the use of drones for this purpose was rated significantly less important at 3.13.

In transporting oil and gas, companies employed IIoT in various devices as sensors and tracking devices to detect leakage while transporting the product, tracking the movement of the tankers during transportation and increasing throughput, as pointed out by Jayasankar et al. (2024). It was also noted that IIoT in the distribution of oil and gas is the most influential technology, with 4.64, indicating that respondents agreed on its applicability in the operations, while big data analytics is the least influential. Generally, it is observed that IIoT/IoT emerges as the most influential technology in all critical activities of the downstream oil and gas operations. Therefore,

organisations should invest in the technology for improvement purposes.

IR4.0 Technologies Implementation in Oil and Gas Downstream Operations

In the establishment of the IR4.0 technologies implementation level, the respondents were asked to rate how their organisation deploy the IR4.0 technologies in the oil and gas downstream operations. The ratings were based on a 5–point Likert scale in which 5 indicate highest level of implementation while 1 indicates the lowest level of implementation. A total of 11 influential IR4.0 technologies in oil and gas downstream operations, as indicated in Table 2, along with their indictors were considered and analysed using the SEM technique in a SMART-PLS 4.1.0.9. The CFA was conducted to analyse the indicator reliability for each dimension of IR4.0 implementation using factor loading as the criteria which should be > 0.7. In the analysis indicatros with loadings < 0.7 were rejected from the model, while those with loadings > 0.7 were retained and considered relevant in measuring their latent variables, as pointed by Cheung et al. (2024). Several indicators were rejected as they had a loading < 0.7, for instance, in the dimension IIoT, indicators such as DT9, DT7, DT5, DT4, DT2 and DT1 were deemed not reliable in measuring the IIoT latent variable for IR4.0 implementation level as indicated in Figure 1.

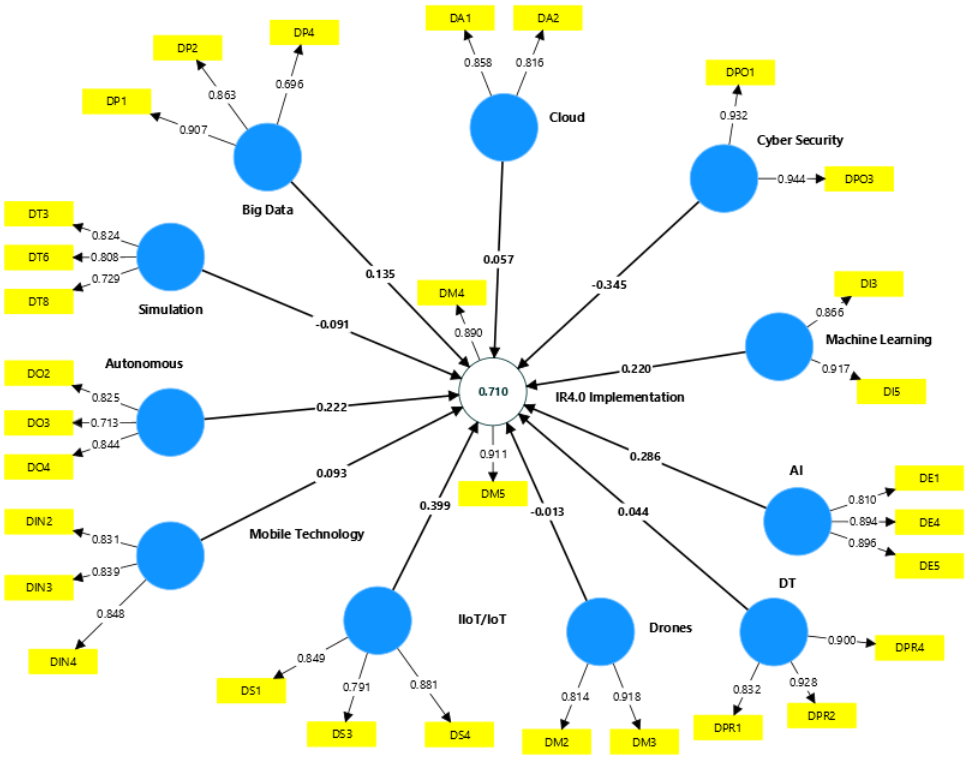

Figure 1. Final Path Diagram for IR4.0 Implementation in Downstream Oil and Gas Operations

The results indicated that, among the technologies, IIoT positively contributes to the implementation level of IR4.0 technologies in oil and gas operations. This is demonstrated by the path coefficient value of 0.399, followed by AI technology with a path coefficient of 0.286, while drone technology is the least contributing technology in the downstream operations, as indicated in Figure 1. This suggests that companies are deploying IIoT technologies in several operations, considering the fact that IIoT is the most influential technology and offer wide range of integration with machines, processes, and devices in several operations (Chelliah et al., 2024). On the other hand, drone technology, which was observed to be the least likely to contribute to IR4.0 implementation level, might have been caused by its infancy stage and the limited functional integration with other devices, processes, and machines.

After CFA analysis, which provides the indicator reliability, measument and structural model were also analysed. For measurement model analysis, Cronbach's Alpha, composite reliability and reliability coefficient were used to assess the internal consistency of the model. The results are indicated in Table 3, in which Cronbach Alpha, composite reliability and reliability coefficient values were greater than 0.7, demonstrating that the indicators consistently measure their latent variable. Moreover, convergent validity of the model was checked using average variance extracted (AVE), with all values being > 0.5, demonstrating that the indicators of the same latent variables are highly correlated, as indicated in Table 3.

Table 3. Internal Consistency and Convergent Validity of the IR4.0 Technologies

IR4.0 Technologies	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
AI	0.835	0.839	0.901	0.753
Autonomous robot	0.712	0.734	0.838	0.733
Big Data	0.779	0.894	0.865	0.784
Cloud	0.774	0.579	0.824	0.701
Cyber Security	0.864	0.870	0.936	0.880
DT	0.867	0.909	0.918	0.788
Drones	0.781	0.748	0.858	0.752
IIoT/IoT	0.794	0.808	0.879	0.708
Machine Learning	0.746	0.773	0.886	0.796
Mobile Technology	0.790	0.792	0.877	0.704
Simulation	0.796	0.708	0.831	0.721

Table 4. Discriminant Validity of the IR4.0 Technologies

IR4.0 Technologies	A	B	C	D	E	F	G	H	I	J	K
AI	0.87										
Autonomous robots	0.40	0.80									
Big Data	0.53	0.36	0.83								
Cloud	0.44	0.58	0.26	0.84							
Cyber Security	0.88	0.33	0.54	0.36	0.94						
DT	0.64	0.33	0.71	0.31	0.56	0.89					
Drones	0.33	0.65	0.28	0.57	0.33	0.30	0.87				
IIoT/IoT	0.78	0.51	0.44	0.45	0.79	0.55	0.53	0.84			
Machine Learning	0.61	0.44	0.42	0.36	0.62	0.51	0.56	0.78	0.89		
Mobile Technology	0.37	0.67	0.20	0.54	0.30	0.28	0.73	0.46	0.51	0.84	
Simulation	0.53	0.24	0.49	0.44	0.45	0.64	0.37	0.42	0.45	0.39	0.79

Moreover, the discriminant validity of the IR4.0 Technologies was also checked using Fornell-Larcker criteria, which indicates that the correlation coefficient of each variable (IR4.0 technologies) in the respective column is greater than any other correlation in the same column, as indicated in Table 4. This demonstrates the fact that the indicators of different IR4.0 technologies are not correlated, thus proving their validity as pointed out by Hair et al. (2022). In the structural model analysis, the coefficient of determination, also called explanatory power (R^2) of the model, was checked to analyse how well the variance of the endogenous valiables are explained by the predictor variables. The results indicated that the value of R^2 is 0.710, which is greater than 0.5, demonstrating that more than 50% of the variance in the endogenous variable (IR4.0 implementation) is explained by its predictors (IR4.0) technologies.

After the CFA, measurement model and structural model analysis, the IR4.0 technologies, which were the dimensions, were further used to establish the IR4.0 technology implementation level in oil and gas downstream operations. The level was established by using Equation (2), which was adopted from Schumacher et al. (2016). Since the indicator weights differ from one another, ten (10) experts in the oil and gas industry who were not involved in the survey were asked to rank the indicators on each IR4.0 dimension as suggested by Schumacher et al. (2016). Using Equation (1), the implementation level of each IR4.0 technology in the downstream oil and gas operations is presented in a radar chart in Figure 2.

The result indicated that among the implemented IR4.0 technologies in the downstream oil and gas operations, IIoT/IoT, simulation and cyber security have the highest implementation level of 3.4, 3.3, and 3.0, respectively. This demonstrates the technology is in medium-level implementation in Tanzania's oil and gas companies specificaaly in the downstream operations. It also unveils that the employment of advanced technologies in the downstream operations is not adequately done, necessitating an increased effort in the same to increase efficiency and effectiveness. Nevertheless, the remaining IR4.0 technologies, which include autonomous robots, cloud computing, digital twin, big data analytics, drones, machine learning, artificial intelligence, and mobile technology, are at the lowest implementation level in the downstream oil and gas operations. This suggests that the downstream operations are still lagging in the employment of IR4.0 technologies, probably due to complexities of the process, the limited skills

available in the organisation, and high investment cost as stipulated by Taifa et al. (2025).

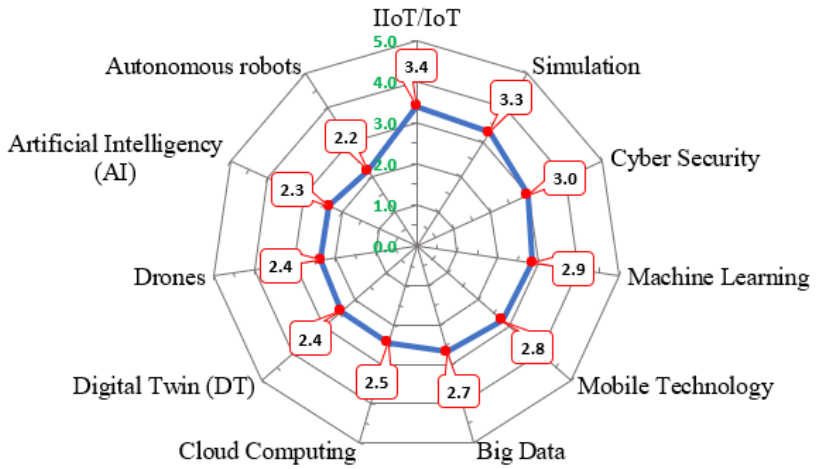

Figure 2. IR4.0 Technologies Implementation Level in the Downstream Oil and Gas Operations

Strategies to integrate IR4.0 technologies in the oil and gas industry

Implementation of IR4.0 technologies in Tanzania's downstream oil and gas industries is an important decision. This is because the integration of IR4.0 technologies into Tanzania's oil and gas (O&G) sector can lead to several advantages, including reducing leakage costs, enhancing safety, improving effectiveness and improving efficiency. The results for the maturity level depict that currently, the oil and gas industry is at a 2.78 maturity level (early integration). This necessitates the need for proposing crucial strategies which can assist the growth of the downstream operations across the industry.

Table 5 depicts the strategies which were proposed through the structured questionnaire, which was sent to experts using a five-point Likert scale and thus analysed descriptively. The most highly ranked strategy (mean = 4.81 out of 5) was on establishing "oil and gas 4.0" core concepts, which should involve adopting IR4.0 technologies such as IoT, BDA and cloud computing for the aim of creating real-time visibility in the operational fields. The second most ranked was in line with the implementation of smart pipeline monitoring (mean = 4.63). This strategy is in line with the findings suggested by Taifa et al. (2025), who explored the applicability of IR4.0 technologies in oil and gas pipeline leakage monitoring. They emphasised the need for implementing smart pipeline monitoring throughout. The least ranked strategy was under the cluster of the regulatory frameworks and governance, where the issue of having an agile framework had a mean score of 2.90. The government should focus on creating a conducive legal and regulatory environment for 4IR innovation, as outlined in the National Digital Economy Strategic Framework 2024-2034.

The strategies were validated using the focus group discussion, which involved 11 experts from the oil and gas industry. Six experts had at least 10 years of experience while working with the oil and gas industry, while the other 5 had worked with the same industry for 5 to 10 years. The experts included engineers with various educational backgrounds, including Bachelor of Science in Petroleum Engineering, Mining Engineering, Industrial Engineering, Chemical and Processing Engineering, while others possessed Master of Science in Oil and Gas, Petroleum Chemistry, Energy Engineering and other related degrees. One member had a PhD in Oil and Gas-related research background. Such demographics demonstrate that the panel members for the focus group discussion were sufficient to carry out one session, which lasted for 5 hours. Prior to the session, all members were distributed with the findings for the earlier two research questions: "What are the influential IR4.0 technologies in the oil and gas industry in Tanzania?" and "What is the IR4.0 technologies' implementation level in the oil and gas industries in Tanzania?" Also, participants signed the consent form that granted permission and their willingness to be involved in the session. On the day of the session, the moderator reminded the participants that the results were mainly for academic purposes and none would be revealed in the document.

Participants discussed the current industrial revolution, Industry 4.0, together with the pertinent technologies, such as AI, autonomous robots, big data, cloud, cyber security, DT, drone technologies, IIoT/IoT, machine learning, mobile technology and simulation, among others. Then, after discussing the results for the influential IR4.0 technologies, they discussed the current implementation level, where the findings revealed an early introduction of the IR4.0 technologies in the Oil and Gas industry. They emphasised the need for setting robust strategies which can influence the implementation of the IR4.0

technologies in the industry so that all oil and gas industry projects can realise all key performance indicators, including quality, financial management (cost implications), timely delivery of the project and fulfilment of the project scope and schedule.

Consequently, through the discussion, the participants agreed that the rating of all strategies in Table 5 was significant and consistent with the real situation. The proposed strategies were all endorsed; however, some emphasis was provided for some strategies, including "*strategic infrastructure and technology investment*", which involves strategic action such as the establishment of "oil & gas 4.0" core, implementing smart pipeline monitoring, cloud-based data management and digital twin utilisation. The IR4.0 technologies are very important to realise the efficiency and effectiveness of the digitalised systems for the oil and gas industry in Tanzania. Participants realised that the provided strategies can assist in accruing the IR4.0 technologies' benefits, should those strategies be implemented in alignment with the vision and mission of the oil and gas sector in the country.

Table 5. Strategies to integrate IR4.0 technologies in the oil and gas industry

Category of the strategy	Strategic action	Description of the strategies	Mean score	Standard deviation
Strategic Infrastructure and Technology Investment	Establishment of "oil & gas 4.0" core	Adopting AI, IoT, Big Data Analytics (BDA), and cloud computing to create real-time visibility of field operations.	4.81	0.372
	Implementing smart pipeline monitoring	Deploying Acoustic Emission (AE) sensors, drones, and autonomous robots for early detection of corrosion, leaks, and vandalism, particularly in critical pipeline infrastructure.	4.63	0.397
	Cloud-based data management	Using cloud platforms to collect and process vast amounts of data from exploration and production, enabling predictive maintenance rather than just reactive repairs.	3.96	0.905
	Digital twin utilization	Developing digital twins for virtual asset management to simulate, monitor, and optimize drilling and production processes.	3.23	1.346
Workforce Development and Skill Upskilling	Bridging the knowledge gap	Training local professionals in data analytics, AI, and cybersecurity to operate advanced technology, reducing reliance on expensive foreign expertise.	3.51	1.182
	Incorporating "soft skills" in engineering	Higher education institutions must offer courses combining technical skills with emotional and social intelligence to create a versatile workforce.	2.93	1.027
Regulatory Frameworks and Governance	Agile policy frameworks	The government is focusing on creating a conducive legal and regulatory environment for 4IR innovation, as outlined in the National Digital Economy Strategic Framework 2024-2034.	2.90	1.949
	Strengthening local content regulations	Aligning the Petroleum (Local Content) Regulations 2017 to promote the adoption of new technologies and facilitate skill transfer from foreign experts to Tanzanian citizens.	3.86	0.909
	Strengthening cybersecurity	Establishing robust cybersecurity frameworks through the National Cybersecurity Strategy and the e-Government Security Operation Centre (eGSOC) to protect critical digital infrastructure.	3.56	0.819
Partnerships and Investment Promotion	International collaborations	Partnering with global stakeholders and international oil companies (IOCs) to bring in advanced technology and best practices.	3.55	0.999
	Public-private partnerships (PPPs)	Encouraging collaboration between the government and the private sector to invest in high-cost digital infrastructure.	3.26	1.188
	State support for investors	Providing incentives for investors who introduce, implement, or support 4IR technologies in the sector.	3.09	1.254
Organizational Change and Cultural Shift	Adopting an "industry 4.0 first" mindset	Shifting corporate culture from traditional, paper-based work to digital, data-driven decision-making.	4.27	0.526

	Creating a data-driven culture	Encouraging knowledge sharing and cross-functional teams to use data analytics for operational improvements.	3.72	0.897

CONCLUSION AND RECOMMENDATIONS

Integration of IR4.0 technologies in the oil and gas industry varies across upstream, midstream, and downstream operations. Research indicates that these technologies are mainly adopted in upstream operations due to risks, high costs, and significant revenue impacts. It can be observed that the oeprations in the downstream section still has not been fully digitalised by implementing IR4.0-related technologies. It is thus vital to digitalise the downstream operations. Therefore, this study focused on assessing the implementation of the IR4.0 technologies for the oil and gas industry in Tanzania. The main finding was that the most important of the IR 4.0 technologies was the IIoT, as it enhances the optimization of downstream operations and improves predictive maintenance. The downstream operations of oil and gas, including storage, distribution, refining, and petrochemical processing, are being transformed by IIoT technologies, which are eliminating manual operations and introducing automation that is data driven and in real time. The integration of sensor networks, edge computing, and AI is enabling downstream operators to enhance asset reliability, improve safety, and optimize logistics to lower operational costs. AI technologies were also noted as influential, while the use of drones was noted as having little influence due to the stage of development. In general, the results indicated that within the Tanzanian oil and gas firms, the implementation levels of IIoT, simulation, and cybersecurity were all at the medium level, suggesting a general delay in the adoption of more sophisticated technologies within IR4.0. This is likely due to the complexities of processes, insufficient levels of skills, and high costs.

The study emphasise on the need for robust and implementable strategies which can be used to foster the integration of IR4.0 technologies in the oil and gas industry. Thus, conclusively, the study found that the top strategy, rated 4.81, the strategy emphasise on the need for establishing the "oil and gas 4.0" core concepts through the adoption of technologies like IoT and cloud computing for real-time visibility. The second-highest strategy focused on smart pipeline monitoring (mean = 4.63), aligning with prior research on pipeline leakage monitoring. The lowest-ranked strategy (mean = 2.90) emphasises the need for agile regulatory frameworks. Other noteworthy strategies include cloud-based data management (3.96), workforce skill upskilling (3.51), and strengthening cybersecurity (3.56). Overall, the government is encouraged to foster a supportive legal environment to enhance 4IR innovation in the sector.

Therefore, the study recommends the implementation of the proposed influential IR4.0 technologies and strategies that can foster the implementation of the IR4.0 in the oil and gas industry. It is expected that the future downstream operations will improve massively. Likewise, despite the fact that the study managed to assess the implementation of IR4.0 in the downstream operations, the other segment of the industry was not covered: these include the midstream and upstream of the oil and gas industry.

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No potential competing interest was reported by the authors.

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article.

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