ENHANCING THE NIGERIAN OIL AND GAS INDUSTRY THROUGH INDUSTRIAL INTERNET OF THINGS ADOPTION.

Onah, Kenneth Nnaemeka[1]; Mbah, Christopher Nwankwo[2]; Onah, Jude Ikechukwu

Department of Engineering Management, Faculty of Engineering, Enugu State University of Science and Technology, Enugu Nigeria[1,3]

[2]Department of Metallurgical and Material Engineering, Faculty of Engineering, Enugu State University of Science and Technology, Enugu Nigeria[2]

Abstract: The oil and gas industry being a complex industry is one of the many areas where Industry 4.0 can be leveraged to optimise its operation. Against this backdrop, this study aims to enhance the adoption of Industrial Internet of Things (IIoT) technologies in the Nigerian oil and gas industry by examining the current level of IIoT integration, identifying the challenges, and assessing its impacts on the industry. The study adopted a descriptive survey design. The population of the study consists of 13,500 professionals in three selected oil and gas companies in Nigeria, representing the national petroleum corporation, Local Oil Companies (LOCs), and International Oil Companies (IOCs). A sample size of 388 professionals was determined using the Yamane Taro method. The findings revealed that IIoT adoption in the Nigerian oil and gas sector is moderate, particularly in areas such as remote monitoring and decision-making, with an overall mean of 3.45 on a scale of 5.00. The major challenges to IIoT implementation include inadequate digital infrastructure, insufficient investment, and lack of skilled personnel, as indicated by a high overall mean of 4.24. Additionally, IIoT adoption has positively impacted the industry by reducing operational downtime, and enhancing safety and decision-making processes, with a mean of 4.10. In conclusion, while the Nigerian oil and gas industry has made progress in adopting IIoT technologies, significant barriers remain, particularly in terms of infrastructure and workforce development.

I. INTRODUCTDION

Background of the Study

The Nigerian oil and gas (O&G) industry has been the bedrock of Nigeria's economy in that it contributes significantly to the Gross Domestic Product (GDP) and foreign exchange earnings. Notably, O&G industry is a very capital-intensive industry with high risk. According to Adeosun, Fagade and Akinleye (2023), the process of production and distribution in the oil and gas industry is highly complex as it utilizes state-of-the-art technology across three distinct levels: upstream, midstream, and downstream. The upstream segment encompasses exploration and production activities, which include geological surveys, onshore and offshore drilling, and the extraction of crude oil and natural gas. Following these initial stages, the midstream segment takes over, focusing on the transportation, storage, and trading of crude oil, natural gas, and their refined products. Finally, the downstream segment deals with the refining of crude oil into usable products, such as gasoline and diesel, as well as the marketing and distribution of these products to consumers and industries (Adeosun, Fagade and Akinleye, 2023). Each of these segments relies on advanced technological solutions to ensure efficiency, safety, and sustainability throughout the entire production and distribution process.

However, despite its economic importance, the O&G industry faces numerous challenges, including aging infrastructure, inefficiencies in production, and security issues such as pipeline vandalism and oil theft. These challenges underscore the need for the adoption of advanced technologies to enhance operational efficiency, safety, and overall productivity. The Industrial Internet of Things (IIoT), a subset of the broader

Internet of Things (IoT), is a significant technological advancement with the potential to transform industrial operations by enabling interconnection of devices and systems.

The adoption of IIoT in the oil and gas industry globally has shown promise in optimizing operations, reducing costs, and minimizing environmental impacts. However, the trend of adoption showed that developing countries are lagging behind (Al-Turjman & Baali, 2019). Thus, the extent of IIoT adoption in Nigeria's oil and gas industry needs to be examined to know whether the potential benefits are on the cause to be fully realised. Moreover, the existing frameworks for IIoT implementation in Nigeria have not been fully explored to ascertain how it is structured, and whether it has the necessary support mechanisms to ensure successful adoption. According to Eneh, Okafor and Ukaoha. (2021), the adoption of IIoT in the Nigerian oil and gas industry comes with manifold impacts on the industry. However, Obi, Igwe and Nwosu (2020) noted that the failure to address the challenges associated with IIoT adoption could result in the underutilization of these technologies, thereby limiting the potential benefits and exacerbating existing operational inefficiencies. To fully harness the benefits of IIoT in the Nigerian oil and gas industry, it is imperative to develop strategies that address the challenges of adoption and implementation (Adeosun, Fagade and Akinleye, 2023).

Conclusively, IIoT has the potential to revolutionize the Nigerian oil and gas industry. However, the realization of this potential is contingent upon addressing the myriad challenges associated with its adoption. The development of a robust framework for IIoT implementation, coupled with targeted strategies to overcome existing barriers, is essential for the industry to fully leverage the benefits of this transformative technology.

Statement of the Problem

The Nigerian oil and gas industry, despite its critical role in the national economy, continues to face significant operational challenges. Most significant among these challenges are; inefficiencies, aging infrastructure, and security threats such as pipeline vandalism and oil theft. These challenges have led to substantial economic losses and have impeded the ability of the industry to operate at optimal efficiency. While the adoption of advanced technologies like the Industrial Internet of Things (IIoT) has the potential to address these issues, the extent of IIoT adoption in the Nigerian oil and gas sector has not been fully ascertained.

Owing to the revolutionary power of the fourth industrial revolution (I40), IIoT has significantly impacted the operations of oil and gas industry globally. Although studies have shown that the oil and gas industry usually lags behind manufacturing in technology adoption, the case of IIoT seems to be different, except for developing economies like Nigeria. One of the major problems that limit technology adoption is dearth of knowledge about the potential impact of the technology. It is against this backdrop that this study deems it imperative to bring the potential impact of IIot in the Nigerian oil and gas industry to the fore to enable the stakeholders in the oil and gas sector to fully understand what they stand to benefit from the technology if widely adopted. Meanwhile, it must also be acknowledged that IIoT is more of a generic name that masks complex data-driven emerging technologies in industrial operations, hence it comes with its own challenges. These challenges must be examined to fully understand them. There is no way the Nigerian oil and gas industry can overcome the myriads of problems bedevilling it without leveraging state-of-the-art technologies like the IIoT. Thus, it is imperative to thoroughly explore how the Nigerian oil and gas industry can improve the adoption of IIoT in the industry.

Given the critical importance of the oil and gas industry to Nigeria's economy, there is an urgent need to address these issues raised and develop effective strategies to promote the adoption and implementation of IIoT technologies. Failure to do so could further exacerbate the operational inefficiencies and economic losses currently faced by the industry, which hinders its growth and competitiveness on the global stage. Hence, this study is tailored towards this direction to contribute to the long-term sustainability and success of the industry.

Aim and Objectives

The aim of the study is enhancing the Nigerian oil and gas industry through IIoT adoption. The specific objectives of the study are to;

i. Examine the extent to which Industrial Internet of Things (IIoT) has been adopted in the operation of Nigerian oil and gas industry.
ii. Examine the challenges associated with the framework for implementing IIoT in the Nigerian oil and gas industry.
iii. Evaluate the impact of adoption of IIoT on the operation of the Nigerian oil and gas industry.

The Research Questions

The study seeks to answer the following research questions;

i. To what extent is IIoT adopted in the operations of Nigerian oil and gas industry?
ii. What are the challenges with the framework for implementing IIoT in the Nigerian oil and gas industry?
iii. How does IIoT impact the operations of Nigerian oil and gas industry?

II. LITERAURE REVIEW

Conceptual Review

Overview of the Industrial Internet of Things (IIoT) in the Energy Sector

The Internet of Things (IoT) facilitates machine-to-machine (M2M) communication over a network without the need for human-to-computer interaction (Elijah et al., 2018). These machines consist of embedded systems equipped with sensors and actuators, which transmit data using various communication technologies via the internet. The M2M communication is enabled by the pervasive presence of computing resources that allow devices to interact through defined communication protocols and architectures (Priyadarshy, 2017). Over the years, IoT has evolved to meet diverse industry requirements, leading to the development of application-specific IoT solutions. This evolution has also paved the way for significant innovations in various industries, introducing the concept of Industrial IoT (IIoT). The IIoT is crucial in the industrial sector, offering efficient and optimized monitoring and control systems that reduce costs and enhance productivity (Khan et al., 2020).

The Industrial Internet of Things (IIoT) is redefining the operations and efficiency of industries worldwide. Within the energy sector, IIoT is particularly significant due to its potential to enhance productivity, optimize resource utilization, and improve safety across various processes (Wanasinghe et al., 2020). The integration of IIoT into energy systems is a critical evolution in Industry 4.0, in that it drives the digital transformation of the sector by enabling real-time data acquisition, advanced analytics, and enhanced operational control. Meanwhile, IIoT refers to the use of interconnected sensors, instruments, and other

devices networked together with industrial applications in mind. These devices are designed to collect, monitor, and analyze data, providing valuable insights that can be used to enhance operational efficiency, predict maintenance needs, and improve safety measures. In the energy sector, IIoT enables the integration of traditional energy systems with digital technologies, creating smart grids, enhancing distributed energy resources, and improving the monitoring of critical infrastructure such as oil and gas pipelines.

The relevance of IIoT to the energy sector lies in its ability to provide comprehensive insights into the operation of industrial equipment and processes which enables proactive decision-making. The technology facilitates the monitoring of energy generation, distribution, and consumption, which allows for more efficient energy management and reducing the risk of system failures. As noted by Alabadi, Habbal, and Wei. (2022), this capability is particularly important in the oil and gas industry, where IIoT can help monitor equipment health, predict failures, and optimize production processes. The applications of IIoT in the energy sector are diverse and impactful. In oil and gas, IIoT technologies are used to enhance asset management, improve safety, and optimize operations. For instance, IIoT enables predictive maintenance by using data from sensors to forecast equipment failures before they occur. This approach not only minimizes downtime but also extends the life of equipment, thereby reducing operational costs (Jia, Wang & Deng, 2022).

More so, IIoT is relevant to the renewable energy sector where it currently finds application in the optimization of smart grids and microgrids. According to Lu et al. (2019), IIoT systems can balance supply and demand more effectively, and improving energy efficiency by integrating real-time data from various energy sources. In a similar vein, IIoT plays a very important role in energy resource management as it helps utilities to monitor energy consumption patterns, detect anomalies, and respond to changes in energy demand dynamically. IIoT is also critical in enhancing the security of energy infrastructures. As these systems become more connected, they are increasingly vulnerable to cyber threats. Ahmed (2022) noted that IIoT provides the tools needed to secure these networks, ensuring that data integrity and system reliability are maintained.

While the benefits of IIoT are clear, its implementation in the energy sector faces several challenges. One of the primary challenges is the integration of IIoT with existing legacy systems. Many energy companies rely on traditional infrastructure that was not designed to accommodate the advanced capabilities of IIoT. Upgrading these systems to be compatible with IIoT technologies can be costly and complex (Wójcicki et al., 2022). Another significant challenge is the issue of data security. As IIoT systems are connected to the internet, they are exposed to potential cyber-attacks. Ensuring the security of data transmission and storage is crucial to protect the integrity of energy systems and prevent unauthorized access to critical infrastructure. This challenge is compounded by the increasing sophistication of cyber threats targeting IIoT networks (Buja et al., 2022). Additionally, the deployment of IIoT requires significant investment in new technologies and training for personnel. Companies must invest in sensors, data analytics platforms, and communication networks to support IIoT operations. Moreover, staff must be trained to understand and utilize these technologies effectively, which can be a time-consuming and costly process (Sreedharan, 2023).

Despite these challenges, the potential of IIoT in the energy sector is vast. As the technology continues to evolve, it is expected to drive further innovations in energy management, sustainability, and operational efficiency.

Theoretical Framework

Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) was originally proposed by Fred Davis in 1986 and further developed by Davis, Bagozzi, and Warshaw in 1989. This theoretical framework has since become one of the most influential and widely applied models for predicting and explaining user acceptance of information systems and technologies. With respect to this study, TAM provides a valuable lens through which to examine the factors influencing the acceptance and implementation of IIoT technologies. The model posits that the intention of an individual to use a technology is primarily determined by two key factors: perceived usefulness (PU) and perceived ease of use (PEOU) (Davis, 1989).

Perceived usefulness is defined as the degree to which a person believes that using a particular system would enhance their job performance, while perceived ease of use refers to the degree to which a person believes that using a particular system would be free of effort (Davis, 1989). These constructs are particularly relevant when examining the adoption of IIoT in the Nigerian oil and gas industry, as they can help elucidate the factors that drive or hinder technology acceptance among industry stakeholders. The TAM has been extensively validated and extended in various technological contexts, including industrial settings (Venkatesh & Davis, 1996). In the context of IIoT adoption, the model can be applied to understand how oil and gas industry professionals perceive the usefulness and ease of use of IIoT technologies in their operations. This understanding can inform strategies to improve adoption rates and overcome implementation challenges.

Moreover, the emphasis of TAM on user perceptions aligns well with the objectives of this study on examining the extent of IIoT adoption and identifying associated challenges. The application of TAM principles in this study will provide insights into the cognitive processes that influence technology acceptance decisions within the Nigerian oil and gas industry. Thus, the Technology Acceptance Model offers a robust theoretical framework for investigating the factors influencing IIoT adoption in the Nigerian oil and gas industry. This study by leveraging the constructs and principles of TAM, contributes valuable insights into the barriers and facilitators of IIoT implementation. The goal of this is to devise strategies to enhance technology adoption and improve industry operations.

Diffusion of Innovations Theory (DOI)

The Diffusion of Innovations Theory (DOI), introduced by Everett M. Rogers in 1962, is a foundational framework for understanding how new technologies, ideas, and practices spread within a social system. This theory explains the process through which innovations are communicated among participants over time, ultimately leading to their adoption or rejection. In the context of this study, DOI provides valuable insights into the adoption of Industrial Internet of Things (IIoT) technologies in the Nigerian oil and gas industry. According to Rogers (2003), the diffusion of innovations is influenced by key factors, including the characteristics of the innovation, communication channels, time, and the social system involved.

The characteristics of the innovation itself play a significant role in determining the adoption rate. For IIoT, relative advantage is one such characteristic, where the technology is perceived to improve operational efficiency, predictive maintenance, and safety outcomes compared to traditional methods (Alabadi, Habbal & Wei, 2022). Compatibility, another key factor, refers to how well IIoT technologies integrate with existing processes and infrastructure within the oil and gas industry (Wójcicki et al., 2022). However,

complexity can hinder adoption, as the Nigerian sector faces challenges with technical expertise and the integration of sophisticated IIoT systems (Jia et al., 2022). Trialability, the ability to pilot IIoT technologies, can facilitate their gradual diffusion (Sreedharan, 2023), while observability; the visibility of IIoT's benefits, such as enhanced production efficiency and reduced downtime-can encourage broader adoption (Buja, Nwankwo & Amosa, 2022).

Communication channels, such as industry conferences, professional networks, and collaborations with international oil companies (IOCs), are critical for spreading IIoT within the Nigerian oil and gas sector (Edem, Nwankwo & Amosa, 2022). Time also plays an essential role, as the innovation-decision process follows stages of knowledge, persuasion, decision, implementation, and confirmation (Rogers, 2003). Regulatory approval, financial resources, and workforce readiness are time-dependent factors influencing IIoT adoption in Nigeria (Isibor et al., 2022). The social system, including government agencies, oil companies, and local communities, also shapes the adoption rate. Key stakeholders such as regulatory authorities and industry leaders play a pivotal role in promoting IIoT adoption (Morocco-Clarke, 2021).

Research Gap

The adoption of Industrial Internet of Things (IIoT) in the oil and gas industry has been the subject of increasing research attention globally. However, there is a notable paucity of research specifically addressing the Nigerian context, which presents unique challenges and opportunities due to its distinct regulatory environment, infrastructure limitations, and economic considerations. While existing literature has explored IIoT adoption in oil and gas sector in developed economies, the transferability of these findings to the Nigerian context remains largely unexplored. This gap in the literature underscores the need for a comprehensive examination of IIoT adoption within the Nigerian oil and gas industry. This is necessary considering the Nigeria's significant role in global oil production and its potential for economic growth through technological advancement.

Furthermore, prior studies have predominantly focused on the technical aspects of IIoT implementation, often overlooking the complex relationship between technological, organisational, and environmental factors that influence adoption decisions in developing economies. The current body of knowledge lacks a holistic understanding of the challenges, impacts, and strategies for improving IIoT adoption specifically tailored to the operational realities of the Nigerian oil and gas industry. This research aims to address these gaps by providing an in-depth analysis of the extent of IIoT adoption, associated challenges, and the operational impacts.

III. METHODOLOGY

Research Design

The study employs a descriptive survey design. This design is appropriate for obtaining detailed and accurate data regarding the current state of Industrial Internet of Things (IIoT) adoption in the Nigerian oil and gas industry. A descriptive survey allows for the systematic collection of information from a sample population. Criswell (2014) asserted that this design helps a researcher to obtain firsthand information from experts who are knowledgeable about the subject matter. This design is particularly suitable for studies aimed at understanding specific phenomena in their natural setting without manipulating variables (Fraenkel and Wallen, 2015). In addition, this method is effective in reaching a larger population, thereby enhancing the generalizability of the findings (Kelley et al., 2003).

Area of Study

The study is carried out in Niger Delta area of Nigeria. The Niger Delta is the delta of the Niger River sitting directly on the Gulf of Guinea on the Atlantic Ocean in Nigeria. It is typically considered to be located within nine coastal southern Nigerian states, which include: all six states from the South-South geopolitical zone, one state (Ondo) from the Southwest geopolitical zone and two states (Abia and Imo) from the Southeast geopolitical zone. The Niger Delta, as now defined officially by the Nigerian government, extends over about 70,000 km^2 (27,000 sq mi) and makes up 7.5% of Nigeria's land mass. Niger Delta region has a population of about 31 million people. More than 90% of oil and gas revenues, 80% of Nigeria's GDP, and 95% of the national budget are generated in the region (Jack and Okouwa, 2013).

Sample and Sampling Technique

The study targets a population of 13,500 professionals from three selected oil and gas companies in Nigeria. The companies are; Nigerian National Petroleum Company Limited (NNPC), Shell Petroleum Development Company of Nigeria (SPDC) and Aiteo Group. The sample size of the study was determined to be 388 using the Yamane Taro method of sample size determination shown in equation (3.1).

$$n = \frac{N}{1 + N(e)^2} \qquad (3.1)$$

Where:

n = the required sample size
N = the population size (13,500)
e = margin of error (set at 5% or 0.05)

A multi stage sampling technique was used to sample the appropriate numbers of respondents from each of the three oil and gas companies. To allocate the sample size proportionally to each company under study, stratified proportional sampling was employed.

IV. RESULTS AND DISCUSSIONS

Evaluation of the First Research Question

The descriptive analysis of Table 1 highlights the extent of IIoT adoption in the operations of the Nigerian oil and gas industry, with a focus on percentages, mean scores, and standard deviations. Out of 388 respondents, only 340 completed their questionnaire and returned in good form. The findings suggest that IIoT is being adopted at a moderate to high level across various operational areas. For instance, 30.3% of respondents strongly agreed that IIoT is extensively used for remote monitoring and control, and 25.6% agreed, resulting in the highest mean score of 3.67 with a standard deviation of 1.15. This indicates a relatively consistent adoption of IIoT for remote monitoring, with a small portion (9.1%) expressing low levels of adoption.

Table 1.

Analysis of the extent IIoT is adopted in the operations of Nigerian oil and gas industry.

Item/ No	Item	VHE (%)	HE (%)	ME (%)	LE (%)	VLE (%)	Tl.	$\bar{x}$	σ
1	To what extent are IIoT technologies used for real-time monitoring of oil and gas operations?	63 (18.5%)	71 (20.9%)	109 (32.1%)	58 (17.1%)	39 (11.5%)	340	3.18	1.25
2	To what extent is IIoT adopted for predictive maintenance of equipment and infrastructure?	81 (23.8%)	74 (21.8%)	110 (32.4%)	46 (13.5%)	29 (8.5%)	340	3.39	1.23
3	To what extent are IIoT solutions integrated into data acquisition processes in this company?	76 (22.4%)	71 (20.9%)	136 (40.0%)	39 (11.5%)	18 (5.3%)	340	3.44	1.12
4	To what extent are IIoT platforms employed to enhance safety in oil and gas operations?	92 (27.1%)	63 (18.5%)	127 (37.4%)	27 (7.9%)	31 (9.1%)	340	3.46	1.22
5	To what extent is IIoT used to optimize energy consumption in the operations of this oil company?	68 (20.0%)	73 (21.5%)	141 (41.5%)	31 (9.1%)	27 (7.9%)	340	3.36	1.14
6	To what extent has IIoT adoption improved decision-making in operational activities of this company?	97 (28.5%)	83 (24.4%)	119 (35.0%)	24 (7.1%)	17 (5.0%)	340	3.64	1.12
7	To what extent does this company rely on IIoT for remote monitoring and control of operations?	103 (30.3%)	87 (25.6%)	102 (30.0%)	31 (9.1%)	17 (5.0%)	340	3.67	1.15
	Grand mean/ Standard deviation							3.45	1.18

Key: VHE = Very High Extent, HE = High Extent, ME = Moderate Extent, LE = Low Extent, VLE = Very Low Extent, TL = Total number of respondents.

The use of IIoT for improving decision-making in operational activities also stands out, with 28.5% strongly agreeing and 24.4% agreeing that IIoT has significantly impacted decision-making processes. This results in a high mean score of 3.64 and a standard deviation of 1.12, demonstrating a strong consensus on the positive influence of IIoT on decision-making, though 7.1% and 5.0% of respondents indicated lower levels of agreement. For safety enhancements through IIoT platforms, 27.1% strongly agreed and 18.5% agreed that IIoT plays a role in improving safety measures, leading to a mean score of 3.46 and a standard deviation of 1.22. Similarly, the adoption of IIoT for predictive maintenance garnered a mean score of 3.39, with 23.8% of respondents strongly agreeing and 21.8% agreeing, though a notable 13.5% felt that the adoption was low. When it comes to energy optimization, 41.5% of respondents felt that IIoT adoption was moderate, while 20.0% and 21.5% rated it as high or very high, resulting in a mean score of 3.36 and a standard deviation of 1.14. The use of IIoT for real-time monitoring received the lowest mean score of 3.18, with 32.1% rating it as moderate, and only 18.5% of respondents indicating a very high level of adoption, reflecting the need for greater integration in this area. The standard deviation of 1.25 indicates a broader variation in the responses. Overall, the grand mean of 3.45 and a standard deviation of 1.18 suggest that IIoT is being moderately adopted across various operational areas in the Nigerian oil and gas industry. While areas like remote monitoring, decision-making, and safety show stronger adoption with over 30% of respondents rating their use as high or very high, other areas, such as real-time monitoring, reveal more variability in adoption levels. This suggests that while IIoT is becoming increasingly integrated into the industry, there are still areas where adoption could be improved.

Evaluation of the Second Research Question

The descriptive analysis of the challenges in implementing IIoT in the Nigerian oil and gas industry as presented in Table 2 highlights several critical areas of concern. A significant 86.2% of respondents strongly agreed that the lack of adequate digital infrastructure is a major challenge, resulting in a high mean score of 4.70 and a low standard deviation of 0.88, indicating strong consensus on this issue. The lack of adequate infrastructure presently stands as the most challenging problem frustrating the massive deployment of IIoT in the Nigeria Oil and Gas Industry.

Table 2.

Analysis of the challenges with the framework for implementing IIoT in the Nigerian oil and gas industry.

Item No	Item	SA (%)	A (%)	U (%)	D (%)	SD (%)	Tl.	$\bar{x}$	σ
1	The lack of adequate digital infrastructure is a major challenge to IIoT implementation in the oil and gas sector.	293 (86.2)	21 (6.2)	5 (1.5)	12 (3.5)	9 (2.6)	340	4.70	0.88
2	There is insufficient investment from companies to support IIoT adoption in the oil and gas industry.	154 (45.3)	132 (38.8)	18 (5.3)	21 (6.2)	15 (4.4)	340	4.14	1.06
3	Regulatory and policy barriers hinder the effective implementation of IIoT technologies in the industry.	171 (50.3)	132 (38.8)	12 (3.5)	16 (4.7)	9 (2.6)	340	4.29	0.94
4	The shortage of skilled personnel in IIoT technologies limits its widespread adoption in the oil and gas sector.	198 (58.2)	127 (37.4)	5 (1.5)	3 (0.9)	7 (2.1)	340	4.49	0.76
5	Concerns over cybersecurity and data privacy are significant barriers to IIoT implementation.	148 (43.5)	136 (40.0)	17 (5.0)	15 (4.4)	24 (7.1)	340	4.09	1.14
6	Resistance to change from employees and management affects the adoption of IIoT technologies.	121 (35.6)	156 (45.9)	34 (10.0)	12 (3.5)	17 (5.0)	340	4.04	1.02
7	The high cost of deploying IIoT solutions is a significant obstacle for companies in the oil and gas industry.	115 (33.8)	153 (45.0)	27 (7.9)	21 (6.2)	24 (7.1)	340	3.92	1.14
	Grand mean/ Standard deviation							4.24	1.00

Key: SA = Strongly Agree, A = Agree, U = Undecided, D = Disagree, SD = Strongly Disagree

Insufficient investment from companies was also seen as a key challenge, with 45.3% strongly agreeing and 38.8% agreeing, contributing to a mean of 4.14 and a standard deviation of 1.06. Although, this challenges is quite significant, however, it is behind inadequate infrastructure. Regulatory and policy barriers were acknowledged by 50.3% of respondents who strongly agreed, and 38.8% who agreed, resulting in a mean of 4.29 and a standard deviation of 0.94. The shortage of skilled personnel was another significant challenge, with 58.2% strongly agreeing and 37.4% agreeing, leading to a high mean of 4.49 and a low standard deviation of 0.76, demonstrating strong consensus.

Concerns over cybersecurity and data privacy were acknowledged by 43.5% who strongly agreed and 40.0% who agreed, but the variability in responses was higher, reflected in a standard deviation of 1.14 and

a mean of 4.09. Resistance to change was also a barrier, with 35.6% strongly agreeing and 45.9% agreeing, resulting in a mean of 4.04 and a standard deviation of 1.02. Finally, 33.8% strongly agreed that the high cost of deploying IIoT solutions was a significant obstacle, while 45.0% agreed, giving a mean of 3.92 and a standard deviation of 1.14. While IIoT technology is expensive, the Nigerian oil and gas industry believed that the lack of massive deployment is not wholly as a result of the cost of the technology itself. Thus, this challenges evidently has the least mean score. The grand mean of 4.24, with a standard deviation of 1.00, underscores overall agreement on these challenges, with infrastructure, investment, and skilled personnel being the most unanimously recognized.

Analysis of the Third Research Question

The descriptive statistical analysis of how IIoT impacts the operations of the Nigerian oil and gas industry as shown in Table 3 indicate a generally positive influence, as reflected in the high mean scores and relatively low standard deviations across the different areas. The overall grand mean of 4.10 with a standard deviation of 1.10 suggests that respondents widely agree on the positive effects of IIoT on various operational aspects, with minimal variability in responses.

Table 3.

Descriptive statistical analysis on how IIoT impact the operations of the Nigerian oil and gas industry.

Item No	Item	SA (%)	A (%)	U (%)	D (%)	SD (%)	Tl.	$\bar{x}$	σ
1	IIoT has significantly improved real-time monitoring and control of operations in this O&G company.	138 (40.6%)	112 (32.9%)	17 (5.0%)	47 (13.8%)	26 (7.6%)	340	3.85	1.30
2	The adoption of IIoT has led to a reduction in operational downtime through predictive maintenance.	132 (38.8%)	143 (42.1%)	14 (4.1%)	32 (9.4%)	19 (5.6%)	340	3.99	1.15
3	IIoT has enhanced safety measures in oil and gas operations of this company by providing real-time data analytics.	147 (43.2%)	138 (40.6%)	7 (2.1%)	27 (7.9%)	21 (6.2%)	340	4.07	1.15
4	IIoT has contributed to cost reductions by optimizing resource utilization in operations of this company.	134 (39.4%)	160 (47.1%)	11 (3.2%)	17 (5.0%)	18 (5.3%)	340	4.10	1.05
5	The integration of IIoT in this company has improved decision-making processes through better data availability.	172 (50.6%)	121 (35.6%)	5 (1.5%)	19 (5.6%)	23 (6.8%)	340	4.18	1.15
6	IIoT has facilitated better coordination and communication between different operational units of this company.	140 (41.2%)	137 (40.3%)	22 (6.5%)	24 (7.1%)	17 (5.0%)	340	4.06	1.10
7	The use of IIoT in operations has improved the efficiency of supply chain management in the industry.	174 (51.2%)	150 (44.1%)	6 (1.8%)	7 (2.1%)	3 (0.9%)	340	4.43	0.71
	Grand mean/ Standard deviation							4.10	1.10

The highest impact is observed in the area of supply chain management, where 51.2% of respondents strongly agree and 44.1% agree that IIoT has significantly improved efficiency. This item recorded the highest mean score of 4.43 and the lowest standard deviation of 0.71, showing a strong consensus among respondents on the positive impact of IIoT in this area. The role of IIoT in improving decision-making

processes also received a high mean score of 4.18, with 50.6% of respondents strongly agreeing and 35.6% agreeing. This reflects the widespread belief that IIoT enhances data availability, which supports better decision-making in the industry. The standard deviation of 1.15 indicates a small variation in responses. Similarly, IIoT's contribution to cost reductions through resource optimization yielded a mean score of 4.10, with 47.1% agreeing and 39.4% strongly agreeing. The relatively low standard deviation of 1.05 suggests consistency in responses, with only a small percentage of respondents disagreeing or being undecided.

The adoption of IIoT for real-time data analytics to enhance safety measures also scored highly, with a mean of 4.07 and 43.2% of respondents strongly agreeing. Despite this, 7.9% of respondents expressed disagreement, indicating some variability in perceptions of IIoT's impact on safety, as reflected by the standard deviation of 1.15. Predictive maintenance, which reduces operational downtime, received a mean score of 3.99, with 42.1% agreeing and 38.8% strongly agreeing. This score, while still high, reflects slightly more variability in responses (standard deviation of 1.15), with a notable 9.4% of respondents disagreeing with the statement.

Finally, the use of IIoT to improve real-time monitoring and control had a mean score of 3.85, with 40.6% strongly agreeing and 32.9% agreeing. However, the standard deviation of 1.30 indicates higher variability in responses, with 13.8% of respondents disagreeing. Overall, the analysis shows that IIoT has a substantial positive impact on the operations of the Nigerian oil and gas industry, particularly in areas like supply chain management, decision-making, and cost optimization. However, there is some variability in perceptions, especially concerning real-time monitoring and predictive maintenance.

Discussion of Results

The findings of this study has shown that IIoT adoption in the Nigerian oil and gas industry is moderately progressing, with varying degrees of implementation across operational areas. Key functions such as real-time monitoring, predictive maintenance, and data acquisition show noticeable levels of adoption, though not uniformly high. This suggests that the industry recognizes the potential of IIoT technologies, but adoption is not yet fully maximized across all sectors. From a theoretical perspective, the findings align with the Technology Acceptance Model (TAM), which highlights perceived usefulness and ease of use as key determinants of technology adoption. In this context, the relatively moderate adoption of IIoT could be attributed to the industry's perception of IIoT's usefulness in improving operational efficiency and decision-making processes. Empirical evidence supports this pattern of gradual adoption. Elijah et al. (2021) highlighted the increasing use of IIoT in the upstream oil and gas sector, particularly for real-time monitoring and predictive maintenance. Their study found that while IIoT is being applied, its use remains focused on specific areas rather than across the entire operation. Similarly, Lu et al. (2019) indicated that the transition of oil and gas industry to a more digitized operational model is underway, but still in the early stages, with IIoT primarily implemented in areas that directly enhance operational efficiency.

Marisov et al. (2019) noted that the potential of IIoT in oil and gas operations had long been limited by technical barriers, but recent advances, particularly in technologies like LoRaWAN, have enabled broader adoption. This aligns with the current findings, where moderate levels of adoption suggest that technical advancements are contributing to more widespread IIoT use. However, the adoption is still focused on critical areas such as safety, decision-making, and energy optimization. Hossein Mohammadrezaei and Zakeri (2020) further emphasized the growing adoption of IIoT in the energy sector, particularly for

improving monitoring and efficiency. Their research found that while the adoption is significant, it remains targeted, mirroring the trend observed in the Nigerian oil and gas industry.

The findings of the study on how IIoT impacts the operations of the Nigerian oil and gas industry reveals a substantial positive influence across various operational areas. The mean scores and high percentage of respondents who strongly agree or agree with the statements suggest that IIoT is perceived to significantly enhance operations, particularly in areas such as real-time monitoring, predictive maintenance, safety, cost optimization, decision-making, coordination, and supply chain management. The highest mean score is recorded in the area of supply chain management, where the use of IIoT is seen to greatly improve efficiency. This is consistent with Lu et al. (2019), who noted that IIoT drives improvements in supply chain processes by enabling real-time tracking and automation, thus reducing delays and improving resource utilization. Similarly, Hossein Mohammadrezaei and Zakeri (2020) emphasized the role of IIoT in enhancing operational efficiency in energy systems, which aligns with the findings related to improved supply chain and decision-making processes. The role of IIoT in facilitating better decision-making through enhanced data availability is also notable. With over 50% of respondents strongly agreeing, it suggests that IIoT technologies provide vital insights that enable more informed decisions. This supports the findings of Elijah et al. (2021), who indicated that IIoT plays a crucial role in providing actionable data in upstream oil and gas operations, thereby improving decision-making capabilities.

Moreover, the findings demonstrated that multiple strategies can significantly improve the adoption of Industrial Internet of Things (IIoT) technologies in the Nigerian oil and gas industry. First, the need for increased investment in digital infrastructure was shown to be an important factor for IIoT adoption. The empirical findings from Inuwa (2022) align with this, showing that inadequate infrastructure is one of the major challenges to Industry 4.0 implementation in Nigeria. Likewise, Lu et al. (2019) underscore the necessity of developing robust digital frameworks for the successful integration of IIoT in oilfield operations, further reinforcing the argument that significant infrastructure investments are critical.

Finally, the results underscore the importance of collaboration between industry stakeholders. This aligns with previous research by Alabadi et al. (2022), which highlights that open collaboration among stakeholders is vital to overcoming the technical and operational challenges of IIoT implementation. Collaborative efforts, such as knowledge sharing and joint ventures, can help bridge the gap between early adopters and those who are more resistant to new technologies. In addition, collaborative frameworks can enable the pooling of resources and expertise necessary to address common challenges, including technological integration and regulatory compliance.

V. CONCLUSION

This study is focused on improving the operations of Nigerian oil and gas industry using Industrial Internet of things (IIoT) which is the basis of the fourth industrial revolution (I40). The study provided several key insight ranging from the extent IIoT is currently adopted in the operations of the Nigerian oil and gas industry, the challenges affecting its adoption, its impact in the industry, to the strategies to improve its adoption. Thus, the study showed that IIoT technologies have been moderately integrated across various operational areas, such as real-time monitoring, predictive maintenance, safety enhancement, and decision-making processes. Similarly, the study revealed several critical challenges, including inadequate digital infrastructure, insufficient investment from companies, regulatory and policy barriers, a shortage of skilled personnel, and cybersecurity concerns. Notably, the lack of adequate digital infrastructure and skilled

personnel were identified as the most significant barriers to IIoT implementation. In sum, while IIoT adoption in the Nigerian oil and gas industry is progressing, significant challenges remain. There is therefore a need to addressing these challenges through targeted strategies to realise the full potential of IIoT in optimising operations, enhancing safety, and improving overall efficiency in the industry.

REFERENCES

Alabadi, M., Habbal, A., & Wei, X. (2022). Industrial Internet of Things: Requirements, architecture, challenges, and future research directions. *IEEE Access, 10*, 66374-66400.

Ahmed, S. (2022). *Resilient IoT-based monitoring system for the Nigerian oil and gas industry* (Doctoral dissertation, INSA de Lyon).

Adeosun, A. A., Fagade, T. J., & Akinleye, T. A. (2023). Enhancing oil and gas operations through digital transformation: Opportunities and challenges in Nigeria. *Journal of Energy Technologies and Policy, 13*(2), 45-56.

Al-Turjman, F., & Baali, I. (2019). Industrial IoT: Challenges, design principles, applications, and future directions. *IEEE Internet of Things Journal, 6*(2), 2171-2192.

Buja, A., Apostolova, M., Luma, A., & Januzaj, Y. (2022). Cyber security standards for the Industrial Internet of Things (IIoT)–A systematic review. *2022 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, 1-6.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). SAGE Publications.

Davis, F. D., & Venkatesh, V. (1996). A critical assessment of potential measurement biases in the technology acceptance model: three experiments. *International journal of human-computer studies*, *45*(1), 19-45.

Davis, F. D. (1989). Technology acceptance model: TAM. *Al-Suqri, MN, Al-Aufi, AS: Information Seeking Behavior and Technology Adoption*, *205*(219), 5.

Elijah, O., Rahman, T. A., Orikumhi, I., Leow, C. Y., & Hindia, M. N. (2018). An overview of Internet of Things (IoT) and data analytics in agriculture: Benefits and challenges. *IEEE Internet of things Journal*, *5*(5), 3758-3773.

Elijah, O., Ling, P. A., Rahim, S. K. A., Geok, T. K., Arsad, A., Kadir, E. A., ... & Abdulfatah, M. Y. (2021). A survey on industry 4.0 for the oil and gas industry: upstream sector. *IEEE Access*, *9*, 144438-144468.

Eneh, N. O., Okafor, J. C., & Ukaoha, K. C. (2021). Assessing the impact of industrial IoT on operational efficiency in Nigeria's oil and gas industry. *Journal of Engineering and Applied Sciences, 16*(4), 112-122.

Edem, M., Nwankwo, O., & Amosa, M. (2022). The National Oil and Gas Excellence Centre – Driving safety, cost efficiency, value addition and sustainability in harnessing oil and gas resources in Nigeria. *SPE Nigeria Annual International Conference and Exhibition*, 303-311.

Fraenkel, J. R., & Wallen, N. E. (2015). *How to design and evaluate research in education* (9th ed.). McGraw-Hill Education.

Hossein, M. N., Mohammadrezaei, M., H., and Zakeri, B. (2020). Internet of Things (IoT) and the energy sector. *Energies*, *13*(2), 494.

Inuwa, H. (2022, August). Industry 4.0 Implementation Challenges in the Nigerian Oil and Gas Industry: An Interpretive Structural Modeling Approach. In *SPE Nigeria Annual International Conference and Exhibition* (p. D031S020R002). SPE.

Isibor, A., Kehinde, A. A., Felicia, O., Tolulope, A. F., Victoria, A. A., & Mercy, U. E. (2022). Achieving sustained performance in the Nigerian oil and gas sector despite exchange rate fluctuations: A VAR approach. *International Journal of Energy Economics and Policy, 12*(1), 223-236.

Jia, Z., Wang, J., & Deng, C. (2022). IIoT-based predictive maintenance for oil and gas industry. *Proceedings of the 2022 6th International Conference on Electronic Information Technology and Computer Engineering*, 78-85.

Jack A, Okouwa P. (2013). The state and development interventions in the Niger Delta region of Nigeria. *International Journal of Humanities and Social Science*, 3(10), 255-263.

Khan, W. Z., Rehman, M. H., Zangoti, H. M., Afzal, M. K., Armi, N., & Salah, K. (2020). Industrial internet of things: Recent advances, enabling technologies and open challenges. *Computers & electrical engineering*, *81*, 106522.

Kelley, K., Clark, B., Brown, V., & Sitzia, J. (2003). Good practice in the conduct and reporting of survey research. *International Journal for Quality in Health Care, 15*(3), 261-266.

Lu, H., Guo, L., Azimi, M., & Huang, K. (2019). Oil and Gas 4.0 era: A systematic review and outlook. *Computers in Industry*, *111*, 68-90.

Marisov, D. A., Zatsepin, A. Y., Marin, E. A., Terleev, A. V., & Larionov, M. Y. (2019). Internet of Things in the oil and gas industry: LoRaWAN technology analysis & use cases (Russian). *PROneft Journal*, *2019*(02), 76-80.

Obi, C. K., Igwe, C. O., & Nwosu, P. E. (2020). Evaluating the barriers to IIoT adoption in Nigeria's oil and gas industry. *Journal of Industrial Engineering Research, 6*(1), 14-22.

Priyadarshy, S. (2017). IoT revolution in oil and gas industry. *Internet of things and data analytics handbook*, 513-520.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Sreedharan, R. (2023). Dealing with applications in Industrial IoT. *International Conference on Information Science and Technology Innovation (ICoSTEC)*, 102-111.

Wanasinghe, T. R., Gosine, R. G., James, L. A., Mann, G. K., De Silva, O., & Warrian, P. J. (2020). The internet of things in the oil and gas industry: a systematic review. *IEEE Internet of Things Journal*, *7*(9), 8654-8673.

Wójcicki, K., Biegańska, M., Paliwoda, B., & Górna, J. (2022). Internet of Things in industry: Research profiling, application, challenges and opportunities—A review. *Energies, 15*(5), 1806-1825.