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The Impact of Internet of Things (lot) on Operational Efficiency of Commercial Banks: Perceived Usefulness and Ease of Use as Mediators

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Abstract

The advent of the Internet of Things (IoT) has sparked a technological revolution that is profoundly impacting numerous sectors, including banking. Despite this, there is limited studies on its application in commercial banks in Nigeria. This research is among the few to examine the impact of IoT adoption and its challenges on business operational efficiency, with perceived usefulness and perceived ease of use of IoT as mediating factors. This study draws on the Technology Acceptance Model (TAM) and integrates challenges of IoT adoption into the TAM to examine the impact of IoT adoption on business operational efficiency. This paper utilised a purposive sampling method and collected 181 data from bank employees in Nigeria. The data was statistically analysed using Jamov/R Studio with the Lavaan package to test the hypotheses. The findings revealed a positive and significant relationship between perceived usefulness and IoT adoption, perceived ease of use and IoT adoption, and IoT adoption and operational efficiency, but showed an insignificant relationship between the challenges encountered and operational efficiency. The study concludes that the adoption of IoT has a significant impact on the operational efficiency in the banking sector. This study contributes to existing literature by offering a nuanced understanding of how IoT can catalyse operational efficiency within the commercial banking sector. The findings highlight the dual-pathway mediation of perceived usefulness and perceived ease of use of IoT adoption and efficiency hierarchy as its central theoretical contributions.

Keywords: Internet of Things, Operational efficiency, Perceived usefulness, Banking Employees, Nigeria

1.0 INTRODUCTION

The advent of the Internet of Things (IoT) has introduced groundbreaking technologies and innovations into various business sectors, revolutionising how organisations operate globally. By embedding sensors and connectivity into everyday devices, IoT enables real-time data collection, analysis, and communication, fostering unprecedented levels of efficiency (Langley et al., 2021). Integrating IoT into the banking sector has the potential to vastly enhance operational efficiency because banks serve as the primary intermediaries between savers and borrowers, facilitating the efficient allocation of financial resources.

This study focuses on the adoption of IoT in Nigeria's commercial banks from the employees' perspective because the sector is one of the cornerstones of the economy that mobilises deposits from customers and provides the necessary capital for investments in various sectors such as agriculture, oil and services, which are essential for economic growth (Nachum & Ogbechie, 2019). The Nigerian banking sector has evolved from semi-formal setups where funds were pooled and managed collectively, transitioning into a dynamic landscape under the regulatory oversight of the Central Bank of Nigeria (CBN) (Chiemeke et al., 2006; Ohiani, 2021). This evolution has seen the sector embrace digitalisation, expand branch networks, and leverage technology to improve customer experiences (Okoye et al. 2020). Despite these advancements, the sector faces significant challenges, including operational inefficiencies and security concerns, which have impeded its ability to deliver optimal services and achieve sustainable growth compared to other developing economies like Ghana (Sedom et al. (2025) and advanced economies such as India and the USA (Asir & Manohar, 2023). IoT offers promising solutions to these challenges by automating processes, improving data management, and enhancing customer experiences (Janssen et al. 2019).

Despite numerous studies highlighting the benefits of IoT adoption in various sectors (Sharma and Sood, 2022). For example, Ammirato et al. (2019) examine the adoption of IoT in Italian banks, while Kisanjara (2023) examines the adoption of IoT on organisational performance in Tanzanian banks. Sedom et al. (2025) investigated strengthening IoT adoption in Ghana, yet there is still a gap in the literature regarding its impact on the operational efficiency of commercial banks in developing economies like

Nigeria. Additionally, no employee-level study in Nigeria has been conducted. This study aims to fill this gap by drawing on the \technology Acceptance Model (TAM) to examine the adoption of IoT and its challenges, with a focus on operational efficiencies in Nigerian commercial banks, using perceived usefulness and perceived ease of use as mediating variables.

The TAM model is particularly suitable for this study as it recognises the importance of perceived usefulness and ease of use in technology adoption, which maximise operational efficiency (Saadé and Bahli, 2005). By leveraging TAM, this paper explores the theoretical complementariness in the relationship among IoT adoption, challenges and business operational efficiency in banks, using the perceived usefulness of IoT and perceived ease of use of IoT as mediating factors. Previous research has demonstrated the applicability of the TAM model across various industries (Al-Emran and Granić, 2021; Uwamariya et al., 2021). It remains a robust framework for predicting user technology adoption behaviours by assessing their perceived usefulness, ease of use and attitudes towards technology. Thus, this study employs the TAM model to assess the adoption of IoT technologies, the challenges associated with IoT adoption, and its impact on operational efficiency in Nigerian banks with perceived usefulness and perceived ease of use of IoT as mediating variables, providing valuable insights into the transformative potential of IoT in the banking sector.

The widespread adoption of IoT has proven to enhance operational efficiency across different industries. For instance, IoT-enabled devices and systems have improved operational efficiency and customer satisfaction in various sectors (Bojjagani et al. 2022). It transforms ordinary objects into intelligent devices capable of communicating and performing tasks autonomously through embedded technologies (Al-Fuqaha et al., 2015). In manufacturing and industrial contexts, IoT adoption, combined with data analytics and information system integration, has been linked to improvements in organisational efficiency, productivity, and competitive advantage (Li et al., 2023). Moreover, IoT adoption supports supply chain integration, which mediates the relationship between IoT use and organisational performance. Enhancing supply chain integration through IoT leads to improved supply chain performance and competitive advantages, which subsequently affect organisational efficiency positively (Mashat et al., 2024).

To the best of our knowledge, this study introduces several novel elements into the research of IoT implementation by first incorporating challenges of IoT adoption into the TAM model to examine their combined effect on operational efficiency in a developing country's banking sector. This study distinguishes itself from closely related research through several specific geographic, theoretical, and methodological advancements. Geographically, while prior studies have examined IoT adoption in other regions, such as Ammirato et al. (2019) in Italian banks and Kisanjara (2023) in Tanzanian banks. Additionally, Parab & Deshmukh (2026) reported the adoption of IoT in Indian small and medium-sized enterprises (SME), which discusses the complex interplay of barriers and drivers affecting IoT adoption. This study is different and fills a critical gap by providing empirical evidence specifically from Nigeria's commercial banking sector.

Unlike Mola & Abebe (2023), who used SEM with AMOS software, this research employs covariance-based Structural Equation Modelling (SEM) in R with the Lavaan package. Thus, this approach was chosen because it allows for the simultaneous analysis of multiple multivariate techniques, including confirmatory factor analysis and path analysis, which are necessary for testing the complex relationships in this specific model. Drawing on the TAM model, we make contributions to the extant literature on IoT adoption and operational efficiency in commercial banks by examining how IoT can enhance operational efficiency. We demonstrate how these technologies foster a more effective and responsive banking environment. Through an in-depth analysis of current IoT implementations, this research provides strategic insights into the advantages that IoT offers to developing countries' banks. The findings underscore the critical role of IoT in driving operational efficiency and its broader implications for the financial industry in Nigeria.

Furthermore, the novelty of this study is its employee-centric perspective. The paper shifts the focus from a general organisational or customer view to an employee perspective, examining how those directly using the IoT perceive its usefulness and ease of use in relation to business efficiency. Empirical evidence from the study confirms a significant positive relationship between IoT adoption and operational efficiency within Nigeria's commercial banking sector. These findings contribute to the expanding body of literature that supports the beneficial effects of IoT technologies on organisational performance, particularly within the banking industry.

The findings advance current knowledge by addressing specific geographic, theoretical, and methodological gaps regarding the implementation of the Internet of Things (IoT) in the financial sector of developing economies. Additionally, the study identifies and explores the challenges faced in adopting IoT technologies within Nigeria's commercial banking sector. While the negative relationship between these challenges and operational efficiency is found to be insignificant, recognising these challenges provides crucial insights for banks aiming to overcome barriers to IoT adoption and maximise its benefits.

This study aims to address the following research questions: 1. 'What is the impact of IoT adoption on operational efficiency in the banking system? Secondly, this paper seeks to answer the following research question: 2. 'How does IoT Adoption Drive Operational Efficiency in Nigerian Commercial Banks: Perceived Usefulness and Ease of Use as Mediators? And finally, 3. 'to what extent do the challenges encountered in IoT adoption significantly impact operational efficiency? The rest of this article is organised as follows. The next section provides a review of the related literature on IoT and operational efficiency. This is followed by a section on the theoretical model underpinning this study and the development of hypotheses. The subsequent section discusses the challenges of IoT adoption in organisations. The research methodology section explains how data was collected and analysed using R Studio. The findings section presents the results of the analysis. The discussion section contextualises these findings within the existing literature and outlines the study's contributions and implications.

2.0 LITERATURE REVIEW

The Internet of Things (IoT) is a contemporary technology inducing rapid transformations across numerous sectors, including agriculture, energy, healthcare, and logistics (Balaji et al., 2019; Goumagias et al., 2021). From optimising renewable energy systems to enhancing patient quality of life through wearable devices, IoT applications have demonstrated a significant capacity to improve operational capacities and decision-making (Motlagh et al., 2020; Tun et al., 2020). The banking sector has also been significantly impacted by this technological revolution, with IoT promising substantial improvements in operational efficiency.

However, for these benefits to be realised, user adoption is paramount. A substantial body of literature confirms that Perceived Usefulness (PU) and Perceived Ease of Use (PEU) are critical determinants of users' behavioural intention to adopt IoT technologies. Studies across diverse contexts, including consumer electronics in India, IoT adoption in Saudi Arabia, and process optimisation in the food industry, consistently find that PU and PEU are the strongest predictors of user acceptance and subsequent adoption (Almazroi, 2023; Chatterjee, 2020; Gao & Bai, 2014; Rotsios et al., 2025). These factors are therefore essential for unlocking the operational efficiencies promised by IoT solutions.

Perceived usefulness and perceived ease of use are consistently identified as significant factors influencing the adoption of Internet of Things (IoT) technologies across various studies. Perceived usefulness directly impacts users' behavioural intention to adopt IoT products and services, as it reflects the degree to which individuals believe that using IoT will enhance their performance or daily activities. Similarly, perceived ease of use affects adoption by shaping how effortless users perceive interacting with IoT technologies to be, which in turn can influence perceived usefulness, as easier use tends to increase the perceived benefits of the technology (Alhassan et al., 2023; Hashim et al., 2022).

The adoption of Internet of Things (IoT) technologies in banking, particularly in relation to perceived usefulness and perceived ease of use, has been examined in various studies with a focus on customer acceptance and behavioural intention. In studies focusing on Indian banks, convenience—which is closely related to ease of use—and social influence have been identified as significant factors influencing IoT adoption, while cost and habits were less influential. This suggests that the practical benefits and user-friendly nature of IoT services are more critical to adoption decisions than financial considerations or established routines (Bajaj et al., 2023). Moreover, research extending technology acceptance models such as the Unified Theory of Acceptance and Use of Technology (UTAUT) in other industries also highlights performance expectancy, akin to perceived usefulness and effort expectancy, like perceived ease of use, as strong positive determinants of IoT adoption intentions, reinforcing the relevance of these constructs across sectors (Ali et al., 2023).

Despite the extensive research on IoT's benefits and the well-documented importance of PU and PEU in driving technology adoption, a significant gap remains in the literature. To date, no study has holistically examined how IoT adoption and its associated challenges impact operational efficiency from the perspective of banking sector employees. Specifically, the role of Perceived Usefulness and Perceived Ease of Use as potential mediating variables in this context remains unexplored, research gaps this study aims to address. Therefore, we proposed the following hypotheses:

H_1: *Perceived usefulness mediates the relationship between IoT adoption and operational efficiency.*
H_2: *Perceived ease of use mediates the relationship between IoT adoption and operational efficiency.*

2.1 Technology Acceptance Model and Hypothesis Development

This study draws on Davis (1989) technology acceptance model (TAM) to examine the relationship between IoT adoption and its challenges on the operational efficiency of commercial banks, with a particular emphasis on the mediating roles of perceived usefulness and perceived ease of use of IoT.

TAM posits that users' acceptance and utilisation of new technology are influenced by their perceptions of its usefulness and ease of use (Davis et al., 1989). The model includes measured scales for technology adoption, comprising PU and PEU. According to TAM, a user's propensity to adopt technology is driven by perceived usefulness, which measures the degree to which a person believes that using a particular system would enhance their job performance, and perceived ease of use, which measures the extent to which a person believes that using the system would be free of effort. Since the inception of TAM, numerous researchers have applied the model in various studies (Scherer, et al., 2019; Graf-Drasch et al., 2022; Gøthesen et al., 2023). For instance, Yilmaz and Hazar (2019) employed TAM to investigate IoT adoption among finance and accounting learners, concluding that IoT innovations increase automation and that participants are inclined to adopt these technologies due to their perceived usefulness and ease of use. Additionally, Salami, et al. (2022) demonstrated that technological advancements significantly impact banking operations in deposit money banks, and that the ease of use of these technologies plays a critical role in their adoption, ultimately enhancing operational efficiency.

TAM asserts that a user's perception of the system's usefulness and ease of use influences their attitude toward the system, which in turn affects their behavioural intention to use the system and leads to actual system usage (Bothma & Mostert, 2023). Despite the extensive research on the impact of PU and PEU on technology adoption, there are no studies to date that investigate the mediating role of these factors in the relationship between IoT adoption and operational efficiency from the perspective of banking sector employees. Therefore, the following hypotheses are proposed:

H_3: *There is a positive relationship between perceived usefulness (PU) of IoT and operational efficiency*.
H_4: *Perceived ease of use (PEU) of IoT has a significantly positive impact on operational efficiency.*
H_5: *There is a positive relationship between the PEU of IoT and the adoption of IoT*
H_6: *PU of IoT impacts positively on the adoption of IoT*

2.2 Challenges Encountered in the Adoption of IoT and Operational Efficiency

The adoption of IoT technologies presents a significant paradox for the banking sector. While offering transformative potential for operational efficiency, its implementation is fraught with challenges that can impede performance. A primary concern is security; the interconnected nature of IoT devices broadens the attack surface, creating vulnerabilities that could expose sensitive financial data if not mitigated by end-to-end encryption and robust authentication (Okafor et al., 2022; Balaji et al., 2019). Furthermore, IoT deployment introduces substantial operational hurdles. These include the large initial financial outlay for infrastructure, the immense data management and storage issues arising from a constant influx of sensor data, and the need for new data models to derive actionable insights (Saxena & Al-Tamimi, 2017; Whitmore et al., 2014).

Beyond technological and financial barriers, human factors are critical. Insufficient employee training can foster a lack of trust and unfamiliarity with new systems, preventing the full utilisation of IoT capabilities (Luthra et al., 2018; Bajaj et al., 2023). These multifaceted challenges—spanning technological, organisational, and human domains—can collectively hinder the effective implementation of IoT and negatively impact operational outcomes (Farhana et al., 2024). Several studies have extended the Technology Acceptance Model (TAM) by integrating additional factors such as social influence, enjoyment, compatibility, and trust, which interact with perceived usefulness and ease of use to shape adoption intentions. For example, perceived ease of use and trust have been found to affect perceived usefulness, highlighting the interconnectedness of these constructs in IoT contexts (Gao & Bai, 2014). In educational settings, factors like compatibility and self-efficacy also influence perceived ease of use and usefulness, thereby affecting students' intention to use IoT services (Alhassan et al., 2023).

Furthermore, challenges and limitations in studying these effects include the variability in the significance of trust and security concerns, which sometimes show an insignificant or indirect role in predicting behavioural intention despite their theoretical importance. Privacy and security issues remain critical concerns but are not always directly linked to perceived usefulness or ease of use in empirical findings (Hashim et al., 2022; Tsourela & Nerantzaki, 2020). Additionally, methodological limitations such as reliance on quantitative methods, limited theoretical frameworks, and small or context-specific samples restrict the generalizability of findings. For instance, some studies note the lack of qualitative approaches and the need for more focused research within specific industries or regions, especially in developing countries (Alhassan et al., 2023; Hashim et al., 2022)

To understand how organisations can overcome these barriers, the Technology Acceptance Model (TAM) provides a crucial theoretical lens. Within this framework, Perceived Usefulness (PU) and Perceived Ease of Use (PEU) are identified as critical mediating variables that shape users' behavioural intentions. Research consistently shows that when users perceive a technology as useful and easy to operate, their intention to adopt it increases significantly (Alhasan et al., 2023). Therefore, while the challenges of IoT adoption can detract from operational efficiency, their impact is likely mediated by employee perceptions. If employees believe IoT systems are useful for their roles and easy to interact with, the negative effects of implementation challenges may be mitigated.

Despite this, to the best of our knowledge, no study has empirically examined the challenges of IoT adoption and operational efficiency using Perceived Usefulness and Perceived Ease of Use as mediating variables within the banking sector. This study addresses this critical research gap. Therefore, we proposed the following hypothesis:

H_7: *The challenges of IoT adoption negatively impact operational efficiency, with perceived usefulness and ease of use as mediating variables.*

Building on the TAM model, structural equation model and extant literature on IoT adoption and challenges, the following conceptual model is proposed that helps to conceptualise the relationship between IoT adoption and its challenges on operational efficiencies within Nigerian commercial banks with perceived usefulness of IoT and perceived ease of use of IoT as mediating factors (see Figure 1).

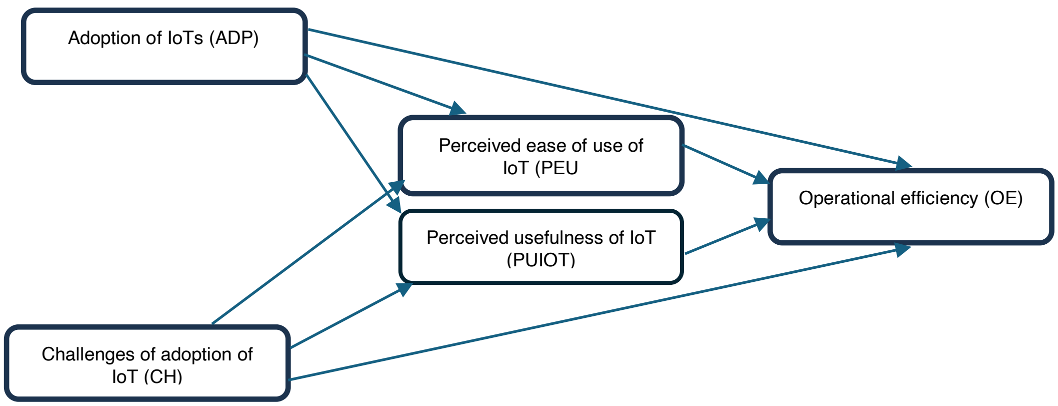

Figure 1 Conceptual Model

Other theoretical models used in technology adoption include the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Theory of Planned Behaviour (TPB). Several studies have empirically compared and combined these models to understand their explanatory power and predictive capabilities (Ali et al., 2025; Hsiao & Tang, 2014; Soliman et al., 2023). For example, Hsiao & Tang (2014) combined TAM, TPB and UTAUT to examine undergraduates' intention to adopt e-textbooks, found that while both TPB and the Technology Acceptance Model (TAM) provided adequate predictive power, TPB was more parsimonious. UTAUT model demonstrated better fit and explanatory power overall, suggesting it may be more effective in predicting behavioural intentions in educational technology contexts. While Ali et al. (2025) combined TAM and Self

Determination Theory (SDT) to explore adoption of the metaverse among higher education institutions. While integrating multiple frameworks can offer depth, utilising the Technology Acceptance Model (TAM) as a standalone framework for IoT adoption in commercial banks provides a more parsimonious, robust, and targeted analysis.By adhering to TAM, the study remains statistically lean, avoiding the multicollinearity issues often triggered by combining models, while still addressing the fundamental reasons why bankers embrace or reject IoT solutions.

The items used to test the impact of IoT adoption and its challenges on operational efficiency, with perceived usefulness and perceived ease of use as mediating variables, were from the existing measurement scales (see Table 1). The measurement items consist of six items, namely, Adoption of IoTs, Challenges of IoTs adoption, Perceived usefulness of IoTs, Perceived ease of use of IoTs and operational efficiency; and the demographic characteristics of respondents (see Table 1).

Table 1 Items and their sources for the questionnaire

Variable	Measurement items	References
Demographic characteristics	Age, Gender, Marital status, educational level, Year in banking (experience), Department, Employment status, Income	1. Salami et al., 2022 2. Usendiah et al., 2022
Adoption of IoT Technologies (ADP)	ADP1-My bank uses applications embedded with IoT technologies. ADP2-My bank's IoT application includes smart ATMs with sensors eg fingerprint sensor. ADP3 My bank's mobile app include IoT features like facial recognition and fingerprint verification for sign-ins. ADP4-My bank's IoT applications include an automated fraud detection system. ADP5- My bank adopts other IoT technologies eg wearables, contactless payments, smart card readers, smart surveillance	1. Ramalingam and Venkatesan, 2019 2. Usendiah et al., 2022

Perceived usefulness of IoT (PUIOT)	PUIOT1 Insights gained from IoT data analytics is applied in decision-making and operations management. PUIOT2-Smart ATMs, which involve using fingerprint sensors to carry out payment, enable instant report transmission and better electronic checks in identifying opportunities for process improvement. PUIOT3- Real-time fraud monitoring and data management are made possible by IoT technologies like sensors, smart ATMs and smartphones. PUIOT4- IoT innovation seeks to ensure that financial experiences are safe and secure. PUIOT5- Data available to the bank via sensors from IoT technologies enables the provision of better service to customers	1. Abu-Dalbouh, 2013 2.Yilmaz and Hazar, 2019 3. Ramalingam and Venkatesan, 2019
Perceived ease of use of IoT (PEU)	PEU1-IoT technologies deployed by my bank are easy to use. PEU2-IoT technologies and applications are user-friendly. PEU3-There is adequate IT support for staff and customers using IoT devices/services. PEU4- It is only someone trained that can work with the backend result of data from diverse sensors. PEU5-I don't find it complicated using and working with data from IoT application.	1. Abu-Dalbouh, 2013 2. Salami et al., 2022 3. Dayour, et al. 2020
Operational Efficiency (OE)	OE1- Banking operations are simplified through IoT technologies. OE2- My bank enhances process consistency by IoT technologies. OE3- Timely, accurate and relevant user information is assured as a result of the use of embedded IoT technologies in their systems. OE4- The bank assures customer satisfaction through efficient operational functions enabled by IoT technologies. OE5- The bank provides secured services by the use of IoT technologies in its processes	1.Rahman, 2023 2.Ramalingam and Venkatesan, 2019
Challenges of IoT utilisation (CH)	CH1- IoT security and data privacy concerns pose a challenge in the fast adoption of IoT technologies in my bank. CH2- Poor funding and a lack of budget for new technologies affect the full adoption of IoT in my bank. CH3-Creation of new models and inadequate storage capacity to accommodate the complex interconnectivity nature of IoT and to incorporate all the information coming from sensors of billions of devices is a challenge to full IoT utilisation in my bank. CH4- Power issues, unreliable internet, and inadequate infrastructures are some of the challenges faced by my bank in the course of the utilisation of IoT technologies. CH5- Inadequate staff training, which sometimes leads to low technological expertise, is a challenge to the full utilisation of IoT in my bank	1. Kunle et al., 2017 2. Okafor et al., 2022 3. Priyadarshini et al., 2022 4. Yilmaz and Hazar, 2019

3.0 METHODOLOGY

This study draws on the TAM model to examine the impact of IoT adoption and its challenges on the operational efficiency of commercial banks, with perceived usefulness and perceived ease of use of IoT as mediating factors. We utilise purposive survey sampling to gather data on the impact of IoT adoption and its challenges on operational efficiency in commercial banks in Nigeria. The purposive sampling approach was used because it allows us to collect significant and standardised data relevant to addressing the aim and objectives of the research (Campbell et al., 2020), from Information Technology (IT) personnel who are responsible for adopting and using IoT efficiently in commercial banks. This allows for the improvement of the representativeness and generalisability of the findings of the research. Also, with digital distribution, we were able to gather data quickly without travel or extensive scheduling, which allowed us to save costs. Furthermore, purposive sampling allows us to intentionally select employees within the IT staff who have knowledge relevant to IoT adoption, ensuring meaningful data.

A pilot study was conducted with few staff which helped to identify the potential issues and areas of improvement in the questionnaire. The pilot sample was included in the final analysis since there was not much difference in the feedback. Additionally, the purposive sampling approach is justified by its alignment with the established Davis (1989) TAM theoretical framework, ensuring that the data collected from the sample were relevant to the constructs of IoT adoption and operational efficiency. The questionnaires were distributed via the Joint Information Systems Committee (JISC) online platform to 200 employees of Nigeria's commercial banks who use IoT technologies in their operations. A total of 181 complete questionnaires were returned, resulting in a 90.5% completion rate.

3.1 Data Analysis

The study employs Covariance-Based Structural Equation Modelling (CB-SEM), a sophisticated multivariate statistical technique, implemented with R Studio/Jamovi and the Lavaan package to derive meaningful insights and conclusions. Lavaan is an R package for classical, covariance-based structural equation modelling (SEM) (Beaujean 2014). Unlike Mola & Abebe (2023), who used SEM with AMOS software to test their hypothesis, we utilised covariance-based SEM in R with the Lavaan package to analyse our data because it integrates several multivariate techniques such as confirmatory factor analysis, path analysis, and regression analysis, which our study requires (Cheung, 2015). Additionally, it performs simultaneous analysis of observed variables, latent variables, their relationships, and their impacts on corresponding outcomes.

Unlike Partial Least Squares Structural Equation Modelling (PLS-SEM), which is more suitable for analysing categorical or ordinal data, non-normal distributions, small sample sizes, and complex models but is less stringent on predictive processes (Akrong et al., 2022), we selected covariance-based SEM for our analysis due to its suitability for confirmatory factor-based analysis. Moreover, we used SEM to analyse both latent and observed variables that measure the perceived adoption of IoT and its challenges on operational efficiency.

Several studies have employed SEM to analyse relationships among variables, including customer relationship management (Bajaj et al., 2023), learning motivation and innovativeness (Almaiah, et al., 2022), big data analytics and operational performance (Al-Khatib, 2022), and supply chain and organisational performance (Lee et al., 2022). Also, missing data was treated by inputting the mean of preceding values.

For Measurement Model (Confirmatory Factor Analysis), these equations define how observed variables (survey items) relate to latent constructs.

IoT Adoption Context:
The definition of variables:

- PU: IoT is useful for banking operations
- PEU: IoT is easy to use for staff
- BI: Employees' intention to use IoT
- AU: Actual IoT usage in the bank

For a latent variable like PU:
$X_i=\lambda_i \cdot PU+\epsilon_i$ ……………………………………………………………………(1)

Where:

- X_i = observed indicator (e.g., survey item)
- λ_i = factor loading
- PU = latent construct (Perceived Usefulness)
- ϵ_i = measurement error

Similar equations are specified for PEU, BI, AU, etc.
$X_i=\lambda_i \cdot PEU+\epsilon_i$ …………………………………………………………………….(2)

$X_i=\lambda_i \cdot BI+\epsilon_i$ ……………………………………………………………………….(3)
$X_i=\lambda_i \cdot AU+\epsilon_i$ ……………………………………………………………………….(4)

For Structural Model (Path Model), these represent the hypothesised relationships between latent constructs:

- $PU = \beta_1 \times PEU + \xi_1$ ………………………………………………………(5)

- $BI = \beta_2 \times PU + \beta_3 \times PEU + \xi_2$ ……………………………………………..(6)
- $AU = \beta_4 \times BI + \xi_3$ ………………………………………………………….(7)

Where:

- β = structural coefficients (path coefficients)
- ξ= structural error terms

3.2 Reliability and Validity

Examining the consistency and precision of the measures used in a study is crucial for determining the reliability and validity of the data in quantitative research. Tavakol and Dennick (2011) state that reliability of data refers to the instrument's ability to measure data consistently, while validity pertains to the extent to which an instrument measures what it is intended to evaluate. Thus, reliability testing assesses the internal consistency of survey items using metrics such as Cronbach's alpha. This metric determines how well each item within a construct or scale correlates with the others. A high Cronbach's alpha value, typically above 0.70, indicates strong internal consistency (Bonett & Wright, 2015).

To further evaluate the construct validity of the questionnaire, factor analysis was employed. Factor analysis helps identify the underlying dimensions or constructs represented by the questionnaire items (Chan & Idris, 2017). This study tested the reliability and validity of the variables, and the results confirmed that the data were both reliable and valid, as presented in the results section.
Ethical approval and consent of participants were obtained before the study was started in September 2023.

■4.0 RESULTS

The purpose of this study is to examine the impact of IoT adoption and its challenges on operational efficiency, using perceived usefulness and perceived ease of use of IoT as mediating variables. The initial stage of the findings presents the results of the reliability and validity tests of the data. To determine the reliability of the dataset, the alpha and omega values should exceed 0.7, with a minimum recommended value of 0.694 and a maximum of 0.867 (Nunnally & Bernstein, 1994). Table 2 shows the alpha values for perceived usefulness of IoT (PUIOT), perceived ease of use (PEU), operational efficiency (OE), challenges of IoT (CH), and adoption of IoT (ADP) as 0.759, 0.754, 0.805, 0.784 and 0.753, respectively. All the alpha values exceed 0.7, indicating that the data is consistent, reliable, and stable.

The average variance extracted (AVE) is used to test convergent validity (Fornell and Larcker, 1981). If the AVE value is greater than 0.5, convergent validity is satisfied (Hair et al., 2017). All variables met the AVE standards, with values above 0.5 (see Table 2). Thus, the validity results confirm that the instruments PUIOT, PEU, OE, CH, and ADP measured what they were intended to measure. This indicates that the latent construct explains at least 50% of the variance in the indicators.

We also determined the composite reliability (CR) of the latent variables. The CR is use to measure the internal consistency of latent variables in structural equation modeling (SEM) (Fu et al., 2022). CR values of 0.70 indicate good reliability and convergent validity. The result of the CR shows that all the latent variables have CR of 0.7 and above, suggesting that the items consistently measure their corresponding construct (See Table 2)

Table 2 Reliability and validity test results

Variable	α	Ordinal α	ω_1	ω_2	ω_3	AVE	CR
PUIOT	0.759	0.846	0.776	0.776	0.787	0.539	0.770
PEU	0.754	0.848	0.798	0.798	0.849	0.591	0.776
OE	0.805	0.873	0.821	0.821	0.856	0.629	0.803
CH	0.784	0.842	0.794	0.794	0.803	0.532	0.776
ADP	0.753	0.842	0.754	0.754	0.726	0.496	0.778

Additionally, discriminant validity was determined for the dataset. The determination of discriminant validity for a study with latent variables is important because it helps to assess and prevent multicollinearity in the dataset (Henseler et al., 2015). Discriminant validity is assessed using two criteria, the Heterotrait-Monotrait ratio (HTMT) and the Fornell-Larcker criterion. This study used HTMT to determine the discriminant validity because the HTMT is able to achieve higher specificity and sensitivity rates than the Fornell-Larcker criterion (Henseler et al., 2015).

The results of the HTMT ratio are shown in Table 3, and they reveal that most of the constructs' values are below the threshold of 0.9, except for PEU and OE, and PUIOT and PEU. This indicates that there is a potential discriminant validity and multicollinearity concerns for these two variables. However, most of the HTMT are below 0.9, indicating that there is minimal issue of multicollinearity and that the existence of the HTMT ratio was discovered. Thus, the results showed that there were no concerns at all in determining the measurement model's reliability and validity.

Furthermore, to ensure there are no issues of multicollinearity, we performed the Variance Inflation Factor (VIF) and Tolerance analysis. The VIF shows the extent of multicollinearity inflates the variance of the estimated regression coefficients. A VIF of 1 indicates no correlation, while values of (>5\) or (>10\) suggest severe multicollinearity that makes coefficients unreliable. High VIFs mean independent variables are highly correlated, reducing model accuracy. While the Tolerance values show how the independent variables variance are not explained by other independent variables, which is also a measure of multicollinearity. A tolerance value of 0.1 and 0.2 shows severe multicollinearity. Our results show that all the VIF and Tolerance are within the acceptable range of less than 5 for VIF and more than 0.2 for Tolerance (see Table 3). This indicates that there are no issues of multicollinearity in the data.

Table 3 Heterotrait-Monotrait ratio (HTMT) correlation test

	PUIOT	PEU	OE	CH	ADP	VIF	Tolerance
PUIOT	1.000					2.00	0.535
PEU	0.808	1.000				1.63	0.509
OE	0.853	0.900	1.000			2.17	0.461
CH	0.431	0.401	0.416	1.000		1.08	0.926
ADP	0.870	0.727	0.741	0.321	1.000	1.77	0.565

4.1 Haman's Single-Factor Test

We also performed Harman's single-factor test to test for common method bias (CMB). To address potential bias stemming from CMB, a concept frequently linked to social desirability (Podsakoff et al., 2012), this study implemented several procedural safeguards. First, to reduce social pressure, participants were guaranteed anonymity and confidentiality; no names or organisational affiliations were collected. A post hoc Harman's single-factor test was performed (Harman, 1976; Podsakoff et al., 2012). The resulting factor analysis revealed that the primary factor accounted for only 18.79% of the variance, which is less than 50%. Since the single factor accounts for less than 50% of the total variance, no single factor emerged as dominant, CMB is unlikely to have significantly distorted the results.

After the common method bias, reliability and validity test, the descriptive statistics of the demographic characteristics in terms of age, gender, marital status, educational level attained, experience in banking, department of operation and income were determined. The percentage of respondents between the ages of 26-35 years had the highest respondents' rate of 38.1%, while respondents earning between 1000000-10,000000 Naira ($653.21-$6532.15) per annual recorded the highest percentage of 70.5% (see Table 4).

Table 4. Demographic statistics frequency table

Criteria	Factor	N	% of Total	Cumulative%
Age	18-25	52	28.70%	28.70%
	26-35	69	38.10%	66.90%
	36-59	60	33.10%	100.00%
Gender	Male	80	44.20%	44.20%
	Female	98	54.10%	98.30%
	Prefer not to say	3	1.70%	100.00%
Marital Status	Single	83	45.90%	45.90%
	Married	91	50.30%	96.10%
	Prefer not to say	7	3.90%	100.00%
Highest Educational Level Attained	PhD	4	2.20%	2.20%
	Masters degree	65	35.90%	38.10%
	Bachelor degree/Higher National Diploma	102	56.40%	94.50%
	Ordinary National Diploma	1	0.60%	95.00%
	Secondary School Certificate	9	5.00%	100.00%
Years of Banking Experience	0-5years	79	44.60%	44.60%
	6-9years	49	27.70%	72.30%
	10 and above years	49	27.70%	100.00%
Department	IT and related department	118	66.70%	66.70%
	General Operations	27	15.30%	81.90%
	Customer Service	9	5.10%	87.00%
	Human Resources	2	1.10%	88.10%
	Marketing	9	5.10%	93.20%
	Other departments	12	6.80%	100.00%
Staff Status	Permanent staff	124	71.30%	71.30%
	Contract staff	50	28.70%	100.00%
Yearly Income	Below 1,000,000naira per annum	30	17.00%	17.00%
	1,000,000 - 10,000,000 per annum	124	70.50%	87.50%
	10,000,001 and above per annum	22	12.50%	100.00%

Table 5 presents further descriptive statistics in terms of the measures of central tendency and measures of dispersion. The findings that all mean values were more than 4.0 suggested that the respondents had favourable perceptions of adoption of IoT technologies. The challenges of IoT (CH) adoptions shows a mean above 4 (see Table 5), indicating that the mean IoT challenges identified within the Nigerian banking sector are issues bordering around unreliable power challenges, unreliable internet and inadequate infrastructures (see tables 5 and table 1).

Table 5. Descriptive statistics of research variables

	N	Missing	Mean	Median	SD	Minimum	Maximum
ADP1	179	2	4.47	5	0.564	3	5
ADP2	179	2	4.35	4	0.736	1	5
ADP3	179	2	4.53	5	0.630	2	5
ADP4	178	3	4.10	4.00	0.937	1	5
ADP5	179	2	4.21	4	0.866	1	5
PUIOT1	179	2	4.24	4	0.673	2	5
PUIOT2	179	2	4.34	4	0.618	2	5
PUIOT3	179	2	4.21	4	0.711	2	5
PUIOT4	179	2	4.42	4	0.588	2	5
PUIOT5	178	3	4.42	4.00	0.625	2	5
PEU1	178	3	4.38	4.00	0.591	2	5
PEU2	177	4	4.36	4	0.598	2	5
PEU3	178	3	4.17	4.00	0.827	1	5
PEU4	179	2	4.25	4	0.724	2	5
PEU5	179	2	4.21	4	0.651	1	5
OE1	178	3	4.48	4.50	0.534	3	5
OE2	179	2	4.30	4	0.650	2	5
OE3	178	3	4.27	4.00	0.668	2	5
OE4	179	2	4.35	4	0.622	2	5
OE5	179	2	4.30	4	0.626	2	5

Table 5. Descriptive statistics of research variables

	N	Missing	Mean	Median	SD	Minimum	Maximum
CH1	178	3	4.12	4.00	0.859	2	5
CH2	177	4	4.08	4	0.895	1	5
CH3	176	5	4.14	4.00	0.798	1	5
CH4	177	4	4.19	4	0.842	1	5
CH5	178	3	4.03	4.00	0.950	1	5

4.2 Goodness-of-fit Measurement

Hair et al. (2012) emphasised that the goodness-of-fit of a model can be determined with the Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), Normed Fit Index (NFI), Tucker-Lewis coefficient (TLI), incremental fit index (IFI), Bentler-Bonett non-normed fit index (NNFI) and relative fit index (RFI). The TLI, CFI, NNFI and RNI values are all above the acceptable level of 0.9 (see Table 6) as proposed by Henseler & Sarstedt (2012). All these indices make the study model considered as good fit.

Table 6. Goodness-of-fit indices

	Model
Comparative Fit Index (CFI)	0.983
Tucker-Lewis Index (TLI)	0.981
Bentler-Bonett Non-normed Fit Index (NNFI)	0.981
Relative Non centrality Index (RNI)	0.983
Bentler-Bonett Normed Fit Index (NFI)	0.966
Bollen's Relative Fit Index (RFI)	0.962
Bollen's Incremental Fit Index (IFI)	0.983
Parsimony Normed Fit Index (PNFI)	0.857
Root Mean Square Error Approximation (RMSEA)	0.0679
Standard Root Mean Square Residual (SRMR)	0.0683

According to Byrne (2016) the Root Mean Square Error of Approximation (RMSEA) and Standard Root Mean Squared Residual (SRMR) help to evaluate the goodness of fit of a model, that is, they help to know the discrepancies between the developed model and the data. The appropriate values are that RMSEA and SRMR values should be less than 0.08. Our results show that both the RMSEA and SRMR are below 0.08 (see Table 6), indicating that the goodness of fit of the model is appropriate.

4.2 Confirmatory Factor Analysis (CFA)

Tables 7 and 8 show the CFA results, which illustrate the relationship between the observed variables of adoption of IoT, perceived usefulness, perceived ease of use, business operational efficiency and challenges of IoT are all significant. This indicates that the measures of the constructs are consistent with the dataset, and the observed variables loaded well with their construct.

Table 7. CFA factor loadings of observed variables

Factor	Indicator	Estimate	SE	Z	p
ADP	ADP1	0.374	0.0410	9.13	< .001
	ADP2	0.525	0.0519	10.12	< .001
	ADP3	0.300	0.0487	6.17	< .001
	ADP4	0.667	0.0669	9.97	< .001
	ADP5	0.521	0.0645	8.07	< .001
PUIOT	PUIOT1	0.458	0.0473	9.68	< .001
	PUIOT2	0.387	0.0447	8.65	< .001
	PUIOT3	0.359	0.0534	6.71	< .001
	PUIOT4	0.354	0.0437	8.10	< .001
	PUIOT5	0.461	0.0436	10.59	< .001
PEU	PEU1	0.457	0.0399	11.44	< .001
	PEU2	0.484	0.0401	12.06	< .001
	PEU3	0.494	0.0609	8.12	< .001
	PEU4	0.285	0.0559	5.09	< .001
	PEU5	0.360	0.0482	7.46	< .001
OE	OE1	0.298	0.0404	7.37	< .001
	OE2	0.431	0.0464	9.28	< .001
	OE3	0.444	0.0473	9.37	< .001
	OE4	0.455	0.0440	10.35	< .001
	OE5	0.460	0.0439	10.46	< .001
CH	CH1	0.479	0.0680	7.05	< .001
	CH2	0.608	0.0668	9.10	< .001
	CH3	0.486	0.0622	7.82	< .001
	CH4	0.583	0.0641	9.10	< .001
	CH5	0.655	0.0720	9.10	< .001

Table 8 Confirmatory factor covariances

		Estimate	SE	Z	P
ADP	ADP	1.000 [a]			
	PUIOT	0.828	0.0511	16.21	< .001
	PEU	0.674	0.0615	10.95	< .001
	OE	0.635	0.0659	9.63	< .001
	CH	0.258	0.0918	2.81	0.005
PUIOT	PUIOT	1.000 [a]			
	PEU	0.734	0.0566	12.96	< .001
	OE	0.780	0.0534	14.60	< .001
	CH	0.295	0.0904	3.26	0.001
PEU	PEU	1.000 [a]			

		Estimate	SE	Z	P
	OE	0.794	0.0514	15.44	< .001
	CH	0.204	0.0913	2.24	0.025
OE	OE	1.000 [a]			
	CH	0.266	0.0897	2.96	0.003
CH	CH	1.000 [a]			

[a] fixed parameter

4.3 Measurement Model

The measurement model shows that the correlation coefficient estimates were all above 0.6, indicating that the relationship between the latent and observed variables are very good (see table 9).

Table 9 Measurement model for research variables

				95% Confidence Intervals				
Latent	Observed	Estimate	SE	Lower	Upper	β	z	p
PUIOT	PUIOT1	1.000	0.0000	1.000	1.000	0.732		
	PUIOT2	1.010	0.0414	0.929	1.091	0.739	24.4	< .001
	PUIOT3	0.889	0.0413	0.809	0.970	0.651	21.5	< .001
	PUIOT4	0.965	0.0438	0.880	1.051	0.707	22.0	< .001
	PUIOT5	1.134	0.0457	1.045	1.224	0.830	24.8	< .001
PEU	PEU1	1.000	0.0000	1.000	1.000	0.849		
	PEU2	1.040	0.0392	0.963	1.116	0.882	26.5	< .001
	PEU3	0.947	0.0345	0.879	1.015	0.804	27.5	< .001
	PEU4	0.669	0.0340	0.602	0.736	0.568	19.7	< .001
	PEU5	0.824	0.0311	0.763	0.885	0.699	26.5	< .001
OE	OE1	1.000	0.0000	1.000	1.000	0.804		
	OE2	0.939	0.0376	0.865	1.012	0.755	25.0	< .001
	OE3	0.930	0.0358	0.860	1.000	0.748	26.0	< .001
	OE4	1.023	0.0377	0.949	1.097	0.822	27.1	< .001
	OE5	1.035	0.0376	0.962	1.109	0.832	27.5	< .001
CH	CH1	1.000	0.0000	1.000	1.000	0.839		
	CH2	0.871	0.0573	0.758	0.983	0.730	15.2	< .001
	CH3	0.825	0.0549	0.718	0.933	0.692	15.0	< .001
	CH4	0.821	0.0549	0.714	0.929	0.689	15.0	< .001
	CH5	0.816	0.0530	0.712	0.920	0.685	15.4	< .001
ADP	ADP1	1.000	0.0000	1.000	1.000	0.767		
	ADP2	0.993	0.0426	0.909	1.076	0.761	23.3	< .001
	ADP3	0.703	0.0405	0.624	0.782	0.539	17.4	< .001
	ADP4	0.943	0.0409	0.863	1.023	0.723	23.1	< .001
	ADP5	0.923	0.0396	0.845	1.000	0.707	23.3	< .001

4.4 Parameter Estimates for Hypothesis Testing

Table 10 summarises the findings of the hypotheses that were tested. The result shows that there is a positive relationship between adoption of IoT and operational efficiency when perceived usefulness (Coef= 0.652, β=0.622, $p<0.05$) and perceived ease of use (Coef= 0.462, β=0.440, $p<0.05$) mediate the relationships. This finding supports hypotheses (H1 and H2) (see Table 10). This indicates that there is an increase in operational efficiency in the commercial banks when staff perceive that the use of IoT is useful and easy to use for their operation. However, there is no direct relationship between the adoption of IoT and operational efficiency (Coef= -0.375, β=0.358, p=0.310) (see table 10). Another interesting finding that emerged from this study is that there is a direct relationship between perceived usefulness of IoT (Coef= 0.777, β=0.707, $p<0.05$) and perceived ease of use of IoT (Coef= 0.593, β=0.626, $p<0.05$) with operational efficiency in commercial banks. These findings support hypotheses 3 and 4. Together, these results provide important insights into the impact of the adoption of IoT on operational efficiency by commercial banks in developing countries. Surprisingly, we did not find support for the direct relationship between the challenges of IoT and operational efficiency as well as when perceived usefulness and perceived ease of use of IoT mediates the relationship between challenges of IoT and operational efficiency (see Table 10 and Table 11).

Table 10 Parameter estimates

Dep	Pred	Estimate	SE	95% Confidence Intervals Lower	95% Confidence Intervals Upper	β	z	p
OE	PUIOT	0.777	0.391	0.011	1.543	0.707	1.988	0.047*
OE	ADP	-0.375	0.370	-1.101	0.350	0.358	-1.014	0.310
OE	PEU	0.593	0.076	0.444	0.742	0.626	7.776	< .001*
OE	CH	-0.031	0.067	-0.162	0.101	0.032	-0.460	0.646
PEU	CH	0.165	0.042	0.083	0.247	0.163	3.943	< .001*
PUIOT	CH	0.130	0.041	0.049	0.211	0.149	3.155	0.002*
PEU	ADP	0.779	0.044	0.692	0.865	0.704	17.655	< .001*
PUIOT	ADP	0.839	0.049	0.742	0.936	0.879	17.009	< .001*
ADP ⇒ PEU ⇒ OE	Indirect	0.462	0.063	0.339	0.585	0.440	7.355	<.001*
ADP ⇒ PUIOT ⇒ OE	Indirect	0.652	0.332	0.002	1.302	0.622	1.965	<0.49*
CH⇒ PEU ⇒ OE	Indirect	0.098	0.028	0.044	0.152	0.102	3.557	<0.001*

Table 11 summarises the findings and shows that hypotheses H1, H2, significant effect between perceived usefulness (PUIOT) and operational efficiency (OE) with (Coef= 0.4105, β=0.3736, $p<0.05$), which also supports H2. The results did not find support for challenges of IoT adoption and Operational efficiency, adoption of IoT technologies and operational efficiency and perceived ease of use of IoT and Adoption of IoT (see Table 11), thereby supporting H3. Finally, challenges in the full utilisation of IoT have a positive significant effect on operational efficiency when perceived usefulness and perceived ease of use are mediating factors, hence, H7 is not supported with (Coeff = 0.098; β=0.102, $p<0.001$).

Additionally, the R-squared value is used to show the predictive power of the model. The result shows that 79.6% of the variables explain the banks' operational efficiency (see Table 11). Ameer Alhasan et al. (2023) assert that a strong effect is visible in the social science context if the R^2 value is higher than 0.64. The result of this study indicates that the model's dependent variables are properly predicted because the R^2 value is 0.796, which is higher than 0.64. Figure 2 shows the path diagram for the results of the analysis that help in addressing the hypotheses.

Table 11 Hypothesis testing of research model (significant at p**=<0.001, p*=<0.05)

Hypothesis	Relationship	Type	Coefficient	p-value	Direction	Decision
H1	ADP ⇒ PUIOT ⇒OE	Indirect	0.652	<0.049*	Positive	Supported
H2	ADP⇒PEU⇒OE	Indirect	0.4620	<0.001*	Positive	Supported
H3	PUIOT→OE	Component	0.7771	<0.047*	Positive	Supported

H4	PEU→OE	Component	0.5930	<0.001*	Positive	Supported
H5	PEU→ADP	Component	-0.7790	<0.001*	Negative	Not supported
H6	PUIOT→ADP	Component	0.8390	<0.001*	Positive	Supported
H4	CH→OE	Direct	-0.0308	0.646	Negative	Not supported
H5	PEU→CH	Component	0.1653	<0.001*	Positive	Supported
H6	PUIOT→CH	Component	0.1301	<0.002*	Positive	Supported
H7	CH⇒PUIOT⇒OE	Indirect	0.1010	>0.05*	Positive	Not Supported
H7	CH ⇒ PEU ⇒ OE	Indirect	0.0980	>0.001	Positive	Not supported
	ADP⇒OE	Direct	-0.375	0.310	Negative	Not significant

R^2-→ OE--→0.796

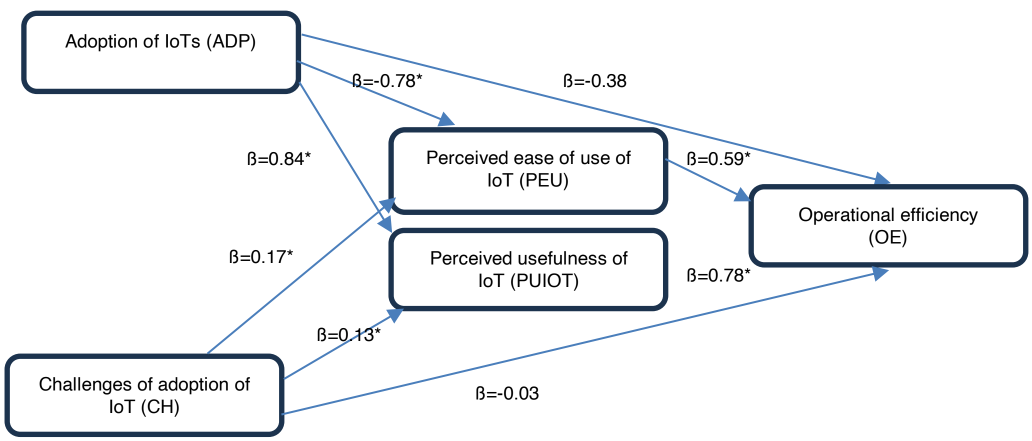

Figure 2 SEM path analysis diagram results

■5.0 DISCUSSION

The purpose of this study was to examine the relationship between adoption of IoT and its challenges on the operational efficiency of commercial banks with perceived usefulness and perceived ease of use of IoT as mediating variables. We seek to address the following research questions:1. 'What is the impact of IoT adoption on operational efficiency in the banking system? Secondly, this paper seeks to answer the research question: 2. 'How does IoT Adoption Drive Operational Efficiency in Commercial Banks: Perceived Usefulness and Ease of Use as Mediators? And finally, 3. 'To what extent do the challenges encountered in IoT adoption significantly impact operational efficiency?

5.1 Impact of IoT on operational efficiency

First, the study found that IoT adoption (ADP) does not have a significant direct impact on operational efficiency (OE) (β= -0.375, p = 0.310). This suggests that simply having the technology or implementing the hardware does not automatically result in improved performance within the banking system. For the banking sector, this implies that the mere presence of IoT devices (like smart sensors or connected ATMs) is insufficient for gain unless paired with specific user-centric factors.

5.2 Perceived Usefulness and Ease of Use as Mediators

Secondly, research question 2 was addressed through the support of H1 and H2. The study reveals that IoT Adoption drives Operational Efficiency only when mediated by user perceptions: Perceived Usefulness (PUIOT): Acts as a strong mediator ($\beta = 0.652$, $p < 0.049$). If bank staff believe the technology makes their jobs more productive, efficiency rises.
Perceived Ease of Use (PEU): Also acts as a significant mediator ($\beta = 0.462$, $p < 0.001$). If the systems are user-friendly, efficiency improves. Essentially, the driver of efficiency is not the technology itself, but how helpful and simple the staff perceives the technology to be.

5.3 Impact of Challenges on Operational Efficiency

The third question was addressed by testing the impact of CH (Challenges) on OE. Interestingly, the results showed that challenges do not significantly impact operational efficiency directly (H4\: $\beta = -0.0308$, $p = 0.646$). Furthermore, the indirect paths (H7) through PUIOT and PEU were also not supported. This suggests that while challenges exist, they are not the primary reason for efficiency failures. Instead, the study indicates that the mental hurdles (lack of perceived utility) are more damaging to efficiency than the technical challenges themselves.

Furthermore, in pursuing the aim of this study, a conceptual model was developed to test seven hypotheses. This study makes four contributions to the literature on IoT adoption and business operational efficiency. First, this study enriches TAM by incorporating the mediating role of perceived usefulness and perceived ease of use of IoT adoption into the relationship between adoption of IoT and its challenges on business operational efficiency. This extension provides a nuanced understanding of how perceived usefulness and ease of use of IoT impact technology is adopted in the banking sector (Davis 1989; Gao & Bai, 2014). Previous research has applied TAM in various contexts, but few studies have examined its application in the context of IoT adoption and its challenges on operational efficiency within commercial banking, particularly in developing countries (Scherer et al. 2019).

Secondly, this article provides actionable insights for banks looking to adopt IoT technologies. It identifies key areas where IoT can enhance operational efficiency fields, thereby guiding strategic investment in technology (Bojjagani et al., 2022). Thirdly, by identifying and analysing the challenges associated with IoT adoption, this article will equip banking institutions with knowledge to mitigate these obstacles, ensuring smoother implementation and greater benefits. Challenges such as data security, integration complexities, and cost have been documented in previous studies, making this contribution highly relevant (Tun et al., 2020).
Fourth, the findings of this study offer valuable insights for regulatory bodies like the Central Bank of Nigeria to formulate policies that encourage IoT adoption while addressing potential risks such as data privacy and cybersecurity, thus, effective regulatory frameworks are crucial for fostering innovation while safeguarding against associated risks (Motlagh et al., 2020).

Overall, this study offers novel insights into the impact of IoT on operational efficiency within commercial banks, by advancing theoretical understanding through the application of TAM, which provides empirical evidence from commercial bank employees and confirms the positive impact of IoT adoption on operational efficiency. Thus, the study contributes to the existing literature by offering a nuanced understanding of how IoT can catalyze operational efficiency within commercial banks.

5.4 Implications of the study

The study on the impact of IoT adoption and its impact on business operational efficiency of the commercial banking sector has practical and theoretical significant implications.

For the banking and financial sectors, this study provides actionable insights into IoT adoption. Banks should not focus exclusively on overcoming technical or financial barriers but must strategically prioritise investments in IoT technologies to enhance operational efficiency (Bojjagani et al., 2022). IoT can optimise processes, improve service delivery, and support real-time decision-making. To maximise these benefits, IoT deployment should shift from being solely IT-led to a collaborative initiative involving HR and operations. Leadership must clearly articulate how IoT systems directly benefit employees to strengthen Perceived Usefulness (PU). Simultaneously, improving Perceived Ease of Use (PEU) requires investment in user-friendly interfaces and comprehensive, hands-on training programs. Moreover, for banks in developing countries, IoT adoption can significantly reduce operational costs and enhance customer satisfaction through real-time data processing and predictive analytics (Tun et al., 2020). These technologies enable service streamlining and personalised customer experiences, positioning banks as technological innovators. This, in turn, provides a competitive advantage by attracting tech-savvy customers and enhancing market reputation (Yilmaz & Hazar, 2019).

The adoption of the Internet of Things (IoT) carries significant policy implications that influence regulatory frameworks, governance, and the broader societal impact. Effective policymaking is essential to facilitate successful IoT adoption, as demonstrated in the context of India, where government regulations and governance structures directly affect citizens' willingness and ability to adopt IoT-enabled devices (Chatterjee, 2019). Also, policymakers should shift focus from mere infrastructure subsidies to digital literacy and utility-based training. Since the study highlights that Perceived Usefulness and Ease of Use are the true drivers of operational efficiency, government grants should prioritise user training programmes over hardware procurement alone.

Furthermore, national IoT frameworks must encourage standardisation and interoperability to reduce user frustration, directly boosting ease of use. By incentivising the development of high-utility IoT solutions that solve specific industrial pain points, regulators can ensure that technological adoption leads to measurable economic gains. Policy should bridge the gap between technical availability and workplace psychological readiness.

Theoretically, this study extends the Technology Acceptance Model (TAM) by framing PU and PEU not merely as predictors of adoption but as mediators between implementation challenges and operational outcomes. It integrates practical barriers to IoT adoption with TAM's cognitive framework, proposing that challenges like cost or security impact efficiency indirectly, through employees' perceptions of usefulness and usability. This perspective explains why technologically sound IoT projects in banks and financial institutions may fail to deliver expected operational gains without employee buy-in.

This study advances current knowledge by addressing specific geographic, theoretical, and methodological gaps regarding the implementation of the Internet of Things (IoT) in the financial sector of developing economies. First, methodologically, this study advances knowledge in the study of IoT adoption in organisational efficiency. Unlike many similar studies that use AMOS software (Gürbüz et al., 2026), this research employs covariance-based Structural Equation Modelling (SEM) in R with the Lavaan package. This allows for a more integrated and simultaneous analysis of various multivariate techniques, including confirmatory factors and path analysis. Secondly, while previous studies have examined IoT adoption in Italian (Ammirato et al., 2019) and Tanzanian banks (Kisanjara, 2023), there was a significant lack of empirical research regarding its impact on the operational efficiency of commercial banks. This study fills that void by providing evidence from one of Africa's most dynamic banking landscapes.

■6.0 CONCLUSION, LIMITATIONS AND FUTURE DIRECTION

6.1 Conclusion

This study draws on the TAM model and uses SEM to examine the impact of IoT adoption and its impact on the business operational efficiency of commercial banks to understand the mediating role of perceived usefulness and perceived ease of use of IoT. The findings confirm a significant positive relationship between IoT adoption and operational efficiency, highlighting that perceived usefulness and perceived ease of use are critical mediators in this relationship. The study's results emphasise the transformative potential of IoT in enhancing operational efficiency within the banking sector, aligning with existing literature that underscores the benefits of IoT in various industries (Baiyere et al., 2020). However, it also identifies several challenges associated with IoT adoption, such as security concerns and technological integration issues, which must be addressed to maximise the benefits of IoT implementation (Yilmaz & Hazar, 2019).

Despite its contributions, the study is limited by its sector-specific focus and cross-sectional design, which restrict the generalizability and temporal scope of its findings. Future research should extend this analysis to other sectors and adopt longitudinal approaches to capture the long-term impacts of IoT adoption. Additionally, investigating the interplay between IoT and other emerging technologies, as well as focusing on customer-centric perspectives, will provide a more comprehensive understanding of IoT's potential in enhancing operational efficiency. This study provides valuable insights into the role of IoT in driving operational efficiency in commercial banks, offering a foundation for future research and practical applications aimed at overcoming adoption challenges and leveraging IoT for sustainable growth and innovation in the banking sector.

6.2 Limitation

This study focuses exclusively on the Nigerian banking sector, which limits the generalizability of the findings to other sectors or countries. This sector-specific focus may not capture industry-specific challenges and opportunities inherent in other contexts. Therefore, future research should explore IoT adoption in different sectors within Nigeria and other developing countries to provide a comparative analysis of its impact on business operational efficiency. This will help identify sector-specific challenges and opportunities, enhancing the generalizability of the findings.

Another limitation of this study is that it adopted a cross-sectional design, providing a snapshot of IoT adoption and its impact on operational efficiency at a specific point in time. This approach may not capture the long-term effects and sustainability of IoT implementations (Botta et al., 2016). Future studies should conduct longitudinal studies to track the long-term impact of IoT adoption on business operational efficiency, offering insights into the sustainability of benefits over time. Methodologically, the absence of qualitative or mixed methods approaches limits our understanding of the specific organisational nuances or human factors behind the failed impact of challenges of IOT adoption on operational efficiency with ease of use as mediating variables (H7). Furthermore, while this study examines the impact of IoT adoption and its challenges on business operational efficiency with perceived usefulness and perceived ease of use of IoT as mediating factors, it does not delve deeply into the technological challenges and security issues associated with IoT implementations. Future research should investigate the data privacy and security aspects of IoT adoption, proposing robust frameworks to mitigate these risks effectively.

Another limitation of this article is that the study primarily focuses on operational efficiency from an organizational perspective, with limited consideration of how IoT adoption affects customer perception and experience in the banking sector. Future research should explore how IoT adoption impacts customer perception and experience, helping banks tailor their IoT implementations to better meet customer needs.

This study mainly addresses IoT adoption and its challenges on operational efficiency in commercial banks without examining how emerging technologies such as AI and blockchain can integrate with IoT to enhance operational efficiency. Future research should investigate how emerging technologies such as block chain and AI can be integrated with IoT to enhance operational efficiency in the banking sector.

6.3 Future Direction

Furthermore, future studies should employ longitudinal designs to track the long-term impact of IoT on efficiency over time. Incorporating mixed-methods or qualitative follow-ups, such as semi-structured interviews, is essential to uncover the underlying reasons for user resistance and the failure of certain indirect paths. To improve generalisability, researchers should utilise stratified sampling across diverse industries and conduct cross-country comparisons to assess geographical variances. Additionally, applying multi-group analysis (MGA) to explore demographic moderators (e.g., age, experience) and developing discipline-specific models will provide more granular insights into how IoT adoption varies across specialized sectors.

By addressing these limitations, future research can build on the current study's findings to offer deeper insights and more comprehensive strategies for leveraging IoT to enhance operational efficiency across various sectors and contexts. Not only did this study make recommendations for future research but we also recommend that commercial banks should adopt IoT to monitor and manage ATM performance to ensure timely maintenance and reduce downtime. Additionally, commercial banks could utilise IoT-enabled systems to monitor and manage customer flow within branches, reduce wait times and improve customer satisfaction.

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Data set availability
Data will be provided upon request from the authors

Ethics have been applied according to the University of Northampton Ethics application process.

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