

Effect of Internet of Things on Sustainable Supply Chain Practice in Nigerian North West

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Abstract - This research investigated the effect of internet of things (IoT) on sustainable supply chain practice in pharmaceutical companies. The main objective of the study is to evaluate the effect of IoT on sustainable supply chain practice in selected pharmaceutical companies. A cross-sectional survey research design was employed, using Structural Equation Modelling (SEM). Data was collected through questionnaire from a sample of 150 respondents of the pharmaceutical companies. A major finding is that there is a positive significant effect of internet of things on sustainable supply chain practice in pharmaceutical companies. It is recommended that, pharmaceutical companies should engage in the use of internet of things technology actively. These will help them to easily enhance sustainable supply chain practice which will in turn lead to a better performance in their organizations.

Key Words: Barcodes, Internet of Things, Radio Frequency Identification, Smart Sensors, Sustainable Supply Chain Practice.

1. INTRODUCTION

Globally, sustainable supply chain management has gained prominence due to increasing environmental awareness and consumer demand for responsible production, distribution and consumption of the pharmaceutical products (Ali et al., 2024; Bhadoriya et al., 2024). This has made many organizations to see the need for integrating advanced digital technologies, green logistics practices and principles of circular economy, in order to mitigate carbon emissions, increase efficiency and reduce waste (Nweje & Taiwo, 2025). The government of different countries of the world and other international organizations are equally

implementing more stringent sustainability regulations that are compelling industries to embrace environmental sustainability, energy efficiency measures, and responsible resources management (Ameh, 2024; Jiang et al., 2024). These initiatives enhances **corporate reputation**, **cost** savings, and long-term resilience, which makes sustainability a key driver of modern global supply chains.

In the light of this global focus on sustainability, the world health organization has equally called for a push in integrating sustainable practices in the pharmaceutical supply chain, to improve efficiency and address environmental and social impacts (World Health Organization, 2021). The trend is also evident in Nigeria, where concerns over pharmaceutical waste generation, inefficiency, ineffectiveness, and handling are growing (Ejeromedoghene et al., 2021). The COVID-19 pandemic further exposed the vulnerabilities in pharmaceutical supply chains and more emphasis are made on the need for resilient and sustainable practices (Bwire et al., 2022).

The Nigerian pharmaceutical companies, comprising of both local manufacturers and importers are essential for providing medications to over 200 million people. However, it faces considerable sustainability challenges such as counterfeit drugs, poor waste management (Ejeromedoghene et al., 2021), environmental contamination, limited access to medicines and lack of transparency (Ogunbanwo et al., 2020; Chukwu & Adibe, 2021). Despite the awareness of regulatory requirements in the Nigerian pharmaceutical companies, compliance and oversight remain inadequate. This has continued to hinder progress towards a truly sustainable pharmaceutical supply chain. This study therefore will explore how Internet of Things (IoT) can be leveraged to address

these challenges and promote sustainable practices within Nigeria's pharmaceutical industry.

The adoption of IoT offers a transformative solution by enabling real-time data access, better inventory management, and improved decision-making (Singh et al., 2022). IoT is a powerful solution that has been used for sustainability challenges in various organizations (Ayeni, 2021) including the pharmaceutical industry (Sharma et al., 2020). IoT-enabled sensors improves supply chain transparency (Ayeni, 2021), ensure real-time tracking of pharmaceuticals to prevent waste and counterfeiting (Ezekwu, 2025), and helps monitor drug expiration and facilitates safe disposal or recycling (Gerrans et al., 2023). Some of the problems identified are delays and shortages, poor waste management, counterfeit and substandard medicines, lack of skills and technology. There are other inconsistent findings in previous studies like that of (Yakubu, 2020; Olotuase et al., 2022; Eze, 2024), which all looked at sustainability challenges in pharmaceutical operations from different perspectives. These problems and inconsistent findings have necessitated the need for a research study to explore the combination effect of different sources of internet of things (radio frequency identification, smart sensors, and barcodes) on sustainable supply chain practice in the pharmaceutical companies.

The main objective of this study is to evaluate the effect of IoT on sustainable supply chain practice in selected pharmaceutical companies in Kaduna. The specific objectives are to:

- i. Examine the effect of Radio frequency Identification (RFID) on sustainable supply chain practice in selected pharmaceutical companies in Kaduna.
- ii. Investigate the effect of Smart sensors on sustainable supply chain practice in selected pharmaceutical companies in Kaduna.
- iii. Determine the effect of Barcodes on sustainable supply chain practice in selected pharmaceutical companies in Kaduna.

Based on the above objectives, the following null hypotheses were derived to guide the study:

H₀₁: Radio frequency identification has no significant effect on sustainable supply chain practice in pharmaceutical companies in Kaduna.

H₀₂: Smart sensors has no significant effect on sustainable supply chain practice in pharmaceutical companies in Kaduna.

H₀₃: Barcodes have no significant effect on sustainable supply chain practice in pharmaceutical companies in Kaduna.

The focus of this study is the pharmaceutical companies in Kaduna North west Nigeria, with

specific interest in Mabro, Dialogue, Zabgayi and Andy Pharmaceutical companies. The selected companies are either involved in manufacturing, marketing, or distribution of pharmaceutical products in Kaduna or other outlets in Kano, Zaria, Katsina and Zamfara State. Out of the forty-nine registered pharmaceutical companies in Kaduna based on data from Pharmaceutical Society of Nigeria (Kaduna Chapter) database, four pharmaceutical firms were selected. The selection of these four pharmaceutical companies located in Kaduna is based on their uniqueness in terms of scale, operational structure, degrees of supply chain integration and their levels of engagement with different digital technologies for sustainability initiatives. They are locally rooted companies with more frequent supply chain operations, and offer accessible and relevant data sources for exploring public health supply chains in a Nigerian context. Studying these firms will help reveal practical challenges and opportunities in implementing sustainable and digital supply chain practices among indigenous pharmaceutical firms.

2. REVIEW OF RELATED LITERATURE

2.1 CONCEPT OF SUSTAINABLE SUPPLY CHAIN PRACTICE.

Sustainable supply chain practices (SSCP) are methods or strategies that are employed by various organizations to ensure that their supply chains operate in an environmentally, economically and socially responsible manner (Sudha et al., 2025). These practices according to (Nguyen et al., 2023) involves a holistic approach to managing the entire supply chain lifecycle, starting from the sourcing of raw materials up to the delivery of finished products to consumers or end users. Nweje & Taiwo (2025) defined SSCP as a system adopted by organizations in prioritizing the reduction of their ecological footprint through the implementation of eco-efficient processes, such as minimizing waste, optimizing resource utilization, and reducing carbon emissions. Solomon et al. (2024) further expand on this by adding that the process of SSCP therefore involves; selecting suppliers who adhere to sustainable practices, incorporating circular economy principles that promote reuse and recycling, as well as utilization of renewable resources.

SSCP has also been defined by (Ezekwu, 2025) as the adoption of policies and strategies by organizations to reduce environmental harm, promote social responsibility, and adhere to global sustainability standards, such as the **UN Sustainable Development Goals (SDGs)**. These practices focus on minimizing waste, optimizing resource use, and ensuring ethical operations throughout the supply chain. According to (Ali et al., 2024) sustainable supply chain practices

involves managing the flow of materials, information, and finances while fostering collaboration among companies. These practices aim to balance **economic, environmental, and social objectives** to enhance long-term competitiveness and sustainability. All these definitions are pointing to a strategic commitment by organizations to integrate environmental sustainability, economic viability and social responsibility into their operational frameworks, which will bring about a more sustainable future for all stakeholders involved. But for the purpose of this study, the definitions by (Nguyen et al., 2023; Ali et al., 2024) will be used as operational definition.

Environmental sustainability emphasizes the minimizing of environmental impact throughout the supply chains. This involves conserving resources, reducing waste and utilizing eco-friendly resources (Majumdar et al., 2021). Recycling, using energy-efficient transportation system and sustainable sourcing of raw materials are some of the practical approaches adopted by some companies to support environmental sustainability (Ziaul and Wang, 2023). Economic viability highlights the importance of maintaining profitability while adopting sustainable practices into the supply chains (Das, 2020). Organizations must strive and balance cost efficiency with sustainability practices through innovations such as sustainable technologies and circular economy models, which minimizes waste and maximizes resource use (Apeji & Sunmola, 2020). Social Responsibility focuses on the ethical treatment of workers and communities involved in the supply chain (Duong, 2022). It involves ensuring safe working conditions, fair labor practices and engaging with local communities to promote social equity (Eyo-Udo et al., 2024). Policies that support fair wages, diversity and upholding of human rights throughout the operations need to be implemented in organizational supply chains (Ahmadi et al., 2017).

2.2 CONCEPT OF IOT TECHNOLOGY

IoT is a network of interconnected devices that communicate through the Internet, enables real-time data collection and exchange, enhancing visibility and efficiency across the supply chain (Kamble, Gunasekaran, & Gawankar, 2018). The Internet of Things (IoT) refers to a network of interconnected physical devices embedded with sensors, software, and other technologies that enable them to collect, share, analyze and interpret data for decision making over the internet without requiring human intervention (Omotayo et al., 2023). This will serve as the working definition of the concept of IoT in this study. The integration of the Internet of Things (IoT) into supply chain management has garnered significant attention

in recent years due to its potential to enhance operational efficiency, visibility, and decision-making processes (Agnusdei et al., 2022), and has revolutionized how companies monitor, control, and manage their supply chains which is in response to the dynamic demands of modern markets and in achieving higher levels of customer satisfaction (Casino et al., 2020). IoT technologies such as RFID, Smart Sensors, and Barcodes, which happens to be the focus in this study offer numerous advantages in SSCP.

Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is a wireless technology that uses electromagnetic fields to automatically identify and track tags attached to objects (Khayyam, et al., 2022). It is a valuable form of IoT technology for sustainable supply chain practice (Raza, 2021), and when RFID tags are attached to products, pallets, or containers, it helps companies to automatically identify and track items as they move along the supply chain (Zelbst, et al., 2019). These tags contain electronically stored information that can be read remotely using RFID readers. RFID tags are been applied in supply chains for real time tracking of materials, automating stock movement and reducing errors, monitoring equipment, enhancing security and combating counterfeit goods in the supply chains (Mondal et al., 2019). Basically, RFID is used in sustainable supply chains to reduce waste and counterfeit goods.

SMART SENSORS

Smart Sensors play important roles in modern supply chains especially in **condition monitoring such as** temperature and humidity, in ensuring product quality of items like foods and pharmaceuticals. These devices are deployed at different points in the supply chain such as in transportation, warehouses, and manufacturing plants. According to (Singh et al., 2022), sensors enable the precise and detailed collection of data, allowing organizations to monitor both the condition and location of goods across the supply chain. Additionally, they enhance inventory management by offering real-time insights into stock levels and movement (Singh et al., 2022). Smart sensors play important role in enhancing transparency for sustainability practice in supply chains.

BARCODES

Barcodes are a form of automatic identification technology that encodes information in a visual format, typically consisting of parallel lines and spaces. They can be scanned to quickly retrieve data about products or items in the supply chain (Sarkar, 2023). Barcodes technologies play a significant role in enhancing operational efficiency within the supply chain. They facilitate the tracking and management of

inventory, which is essential for maintaining a lean supply chain environment (Kubanova et al., 2022). Barcodes are often used in conjunction with RFID technologies to provide a comprehensive solution for automatic identification and tracking. This integration allows for more robust data collection and management, leading to improved decision-making and operational efficiency. Barcodes are essential tools that contribute towards enhancing operational efficiency and agility through their strategic implementation and integration with RFID technologies (Nador, 2021).

2.3 EMPIRICAL REVIEW

Eze (2024) studied supply chain disruption and sustainability of pharmaceutical firms in Anambra state, Nigeria. The study adopted a **mixed method research design** which combines the **qualitative interviews** and **quantitative survey analysis**, to explore the impact of supply chain disruptions on fifty (50) selected pharmaceutical firms in Anambra State. The study found that disruptions in Anambra State's pharmaceutical firms supply chain is majorly caused by importation delays, inventory management challenges, poor infrastructure and unreliable suppliers. These disruptions significantly reduced the firms' financial performance, operational efficiency, and regulatory compliance, which in turn threatens their overall sustainability effort.

The author therefore recommends that pharmaceutical firms in Anambra State diversify their supply sources, invest in infrastructure, improve inventory management system, strengthen supplier relationships and most importantly integrate technologies to build resilience against disruptions. He equally urged government and regulatory bodies to provide policy support and incentives that will enhance industry's sustainability and operational efficiency. Despite these findings and recommendations, one of the limitations of the study is that the sample is geographically limited to **Anambra State**, which may not reflect conditions in other regions of Nigeria or West Africa. Sample size of 50 could be considered small for generalizing across the entire pharmaceutical industry. Also, some themes, such as **technology adoption** and **risk modeling** were mentioned but not deeply explored. The integration of **digital twin** or **IoT- based technology** could broaden the scope.

IoT devices such as RFID, Barcodes and Smart Sensors according to (Ayeni, 2021) can provide real-time tracking of shipments and inventory levels. This capability can help firms monitor the status of their products during transportation, reducing delays caused by customs clearance and transportation issues. By having visibility into the supply chain, operational efficiency can be achieved because firms can

proactively address potential disruptions before they escalate, and this is also supported by (Tera et al., 2024). IoT-enabled platforms can streamline information sharing, ensuring that all parties are aware of any changes or issues that may arise, thus improving coordination and response times. The integration of IoT can generate vast amounts of data that can be analyzed to identify patterns and trends in supply chain performance. This data-driven approach can help firms make informed decisions regarding inventory management, supplier selection, and logistics optimization, ultimately leading to improved operational efficiency and reduced costs. With the use of IoT technology, firms can improve operational efficiency, reduce costs, and better meet the healthcare needs of the population.

Yakubu (2020) conducted an analysis of loopholes in the pharmaceutical supply chain, and methods for improving control of counterfeit drugs in Nigeria. The study addressed the critical issues of counterfeit drugs in Nigeria, defining counterfeit drugs as those that are expired, mislabeled, improperly stored, or produced under poor conditions. The study utilized both qualitative and quantitative research methods where twenty (20) participants were interviewed and a survey distributed to 370 individuals comprising of pharmacists and consumers. The study found that there are several loopholes in the Nigerian pharmaceutical supply chain such as a greater number of unqualified workers compared to qualified ones, the presence of open markets that facilitate the sale of counterfeit drugs and poor enforcement of existing laws and regulations. The researcher therefore recommends the enhancement of consumer awareness, increasing familiarity with anti-counterfeit technologies among industry experts, and exercising greater diligence in drug sourcing. One limitation of the study is that it didn't provide **detail explanations of data collection and analysis methods** that will enhance replicability and credibility. However, based on recommendations for further research, this research will investigate the effect of technology (IoT) on sustainable supply chains practices in pharmaceutical companies.

Olutuase et al. (2022) conducted a comprehensive search of relevant studies published between January 2005 and August 2020, on the challenges faced by medicines and vaccines supply chains in Nigeria. The study identified issues such as frequent shortages of essential medicines and vaccines poor inventory management system, infrastructural issues, financial constraint and insufficient trained personnel as part of the major challenges hindering efficiency of pharmaceutical supply chains in Nigeria. The study utilized a scoping review methodology, following the guidelines set by the Joanna Briggs Institute, to

systematically explore and summarize the challenges associated with medicines and vaccines supply chain systems in Nigeria. A comprehensive search was conducted in databases like Scopus and Web of Science for relevant studies published between January 2005 and August 2020, with a focus on original research and reviews, while employing a two-stage screening process to select articles for inclusion. Though the study is quiet comprehensive and robust in terms of reviewing relevant studies published within 15 years, there is still a concern that the findings may not fully represent the challenges faced in all regions of the country and rural areas, as many studies included in the review primarily focused on urban settings of advanced regions where related studies have been conducted. This potentially underestimates the difficulties experienced in less accessible regions. Therefore, there is a need for research studies that will look at the role of technologies such as IoT which can enable real time monitoring of medicines and vaccines, automate inventory management by providing accurate data on stock levels and enhance transparency in the supply chain by allowing stakeholders to track the movement of medicines and vaccines from manufacturers to end-users. Integrating IoT into the medicines and vaccines supply chain in Nigeria can significantly improve efficiency, reliability, and access to essential health products, ultimately contributing to better health outcomes.

2.4 THEORETICAL REVIEW

The theory underpinning this study is the Complex Adaptive Systems (CAS) theory. It explains how systems composed of independent agents interact and adapt to changes in their environment. Introduced by early scholars like Herbert Simon (1960s), who proposed concepts such as bounded rationality in decision-making, the theory emphasizes decentralization, non-linear interactions, feedback loops, and emergent behaviors (Yang et al., 2019; Shi et al., 2021). CAS are resilient systems that evolve over time, maintaining complexity and stability through distributed control and adaptive responses (Touboulic et al., 2018; Statsenko et al., 2018; Yaroson et al., 2021; Jeong & Choi, 2023).

In the pharmaceutical supply chain, agents such as manufacturers, regulators, distributors and patients interact dynamically, influencing the flow of goods and information (Alshemari et al., 2020). Digital technologies like blockchain, IoT, and AI enable real-time monitoring, adaptability, and visibility, allowing agents to optimize operations and respond to challenges such as shortages or inefficiencies (Radmanesh, 2022; Basu, 2021). Feedback loops from these technologies, such as IoT-based alerts for temperature-sensitive drugs, help prevent waste and

enhance supply chain resilience (Attaran, 2020; Abouzid & Saidi, 2023). CAS theory supports this understanding by explaining how adaptive behavior and complex patterns emerge from agent interactions, making it a valuable framework for analyzing digital transformation in Nigeria's pharmaceutical supply chains (Shi et al., 2021).

Complex Adaptive Systems (CAS) theory offers a comprehensive view of the Nigerian pharmaceutical supply chain by emphasizing the interconnectedness of stakeholders, technologies, and external factors. It captures the complex interactions and feedback loops that shape supply chain behavior and performance. This makes CAS a suitable framework for analyzing how digital technologies influence sustainability in the Northwest Nigerian pharmaceutical sector. By applying CAS, stakeholders can better understand and manage the impacts of innovation, regulation, and socio-economic factors to build more resilient and sustainable supply chains.

2.5 CURRENT CHALLENGES AND GAPS IN NIGERIAN PHARMACEUTICAL SUPPLY CHAINS

The Nigerian pharmaceutical supply chain is characterized by fragmentation and inefficiency, with poor coordination between different stages of the supply chain (Oyedijo et al., 2021). This fragmentation is exacerbated by a lack of effective collaboration among supply chain partners, leading to suboptimal distribution and inventory management practices. The public sector supply chain, in particular, suffers from inefficiencies, including late order placement, delays in payment, and poor supplier lead times (Olutuase et al., 2022). These issues contribute to frequent stock-outs of essential medicines at public health facilities. Another key challenge is the lack of automated systems to handle power failures and insufficient temperature monitoring during storage and distribution (Chukwu & Adibe, 2021). Counterfeit and substandard medicines are a significant problem in Nigeria, undermining the integrity of the pharmaceutical supply chain (Eruaga et al., 2024). The lack of robust regulatory enforcement and poor quality control mechanisms exacerbate this issue.

The presence of counterfeit drugs is further facilitated by weak borders and inadequate distribution systems, making it difficult to track and authenticate medicines (Adigwe et al., 2022). Additionally, the lack of harmonized regional regulatory standards and limited access to laboratory facilities for testing and surveillance further undermine the quality control framework (Eruaga et al., 2024). The lack of expertise in areas such as lean innovation, six sigma, and digital transformation further hinders the industry's ability to

adopt modern supply chain practice (Hundal et al., 2021; Oyedijo et al., 2021) (Eruaga et al., 2024). Digital technologies, such as Internet of Things (IoT) and block chain offer promising solutions for enhancing the transparency, traceability, and efficiency of the pharmaceutical supply chain in Nigeria (Ashiwaju et al., 2023). IoT enabled sensors have the potential to combat counterfeit medicines by providing a secure and tamper-proof record of drug distribution (Labaran & Hamma-adama, 2021). However, the adoption of such technologies is hindered by low awareness and the lack of conducive infrastructure (Labaran & Hamma-adama, 2021). The Nigerian pharmaceutical industry faces significant challenges in its supply chain management and sustainability practices. These challenges are rooted in financial constraints, inadequate infrastructure, weak regulatory frameworks, and environmental sustainability concerns. However, there are opportunities for improvement through the adoption of digital technologies, lean and agile practices, and resilience-based approaches. Addressing these challenges will require a coordinated effort from government agencies, private sector stakeholders, and international organizations to create a more efficient, sustainable, and resilient pharmaceutical supply chain in Nigeria.

3. METHODOLOGY

The study adopted a cross-sectional survey research design. **Cross-sectional survey** is a **quantitative research approach** where data is collected from a population or a subset representative, **at a single point in time** (Hunziker & Blankenagel, 2024). The population of this study consist of employees from four selected pharmaceutical firms in Kaduna namely: Mabro Pharmacy, Dialogue Pharmacy, Zabgayi Pharmacy, and Andy Pharmacy, with a total of 150 staff members. Given the manageable population size, a census sampling technique was employed, ensuring that all employees from the selected firms participated in the study. This approach eliminated the need for a sampling formula and enhanced the comprehensiveness of the findings. Primary data was collected through a structured questionnaire that ensures broad representation across the selected pharmaceutical firms.

Internet of things (independent variable) dimension (radio frequency identification, smart sensors and barcodes) were measured using a five-point Likert scale questionnaire. Radio frequency identification was adapted from the works of (Ali, 2024) containing 4 items, smart sensors was adapted from the works of (Ning & Yao, 2023) containing 4 items and barcodes was adapted from the works of (Adeyeye et al., 2023) containing 4 items. Sustainable supply chain practice

(dependent variable) was measured as a one-dimensional variable using a five-point Likert scale questionnaire adapted from the works of (Ikegwuru & Elvis, 2023) containing 4 items. This five point Likert scale questions ranges from strongly agree (SA), to strongly disagree (SD), with 5 as the highest or strongest, and 1 as the lowest or weakest. The questionnaire was subjected to validity and reliability tests using the average variance extracted (AVE), convergent and discriminant validity and the results of the tests were reported in the next section. Copies of the questionnaire were self-administered to Employees of pharmaceutical companies in Kaduna. The study applied the partial least square-structural equation modelling (PLS-SEM) to analyze the data collected from the respondents. The choice of this technique is based on the fact that it absorbs distributional assumption (i.e normality) otherwise required when the ordinary least square (OLS) regression were to be applied. The model for the PLS-SEM is depicted pictorially below:

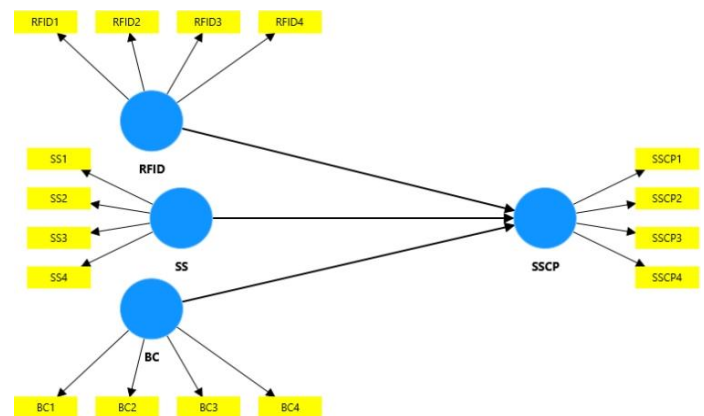


Fig. 1: Conceptual model of the effect of internet of things on sustainable supply chain practice in pharmaceutical companies in Kaduna.

4. RESULTS AND DISCUSSIONS

Table 4.1: Response Rate

Category	Frequency	Percentage
Distributed copies of questionnaire	150	100%
Returned copies of questionnaire	138	92%
Unreturned copies of questionnaire	12	8%
Unusable copies of questionnaire	4	3%
Usable copies of questionnaire	134	89%

Source: SmartPLS Output, 2025

As detailed in Table 4.1, the final usable response rate is 89 percent. A 30 percent response rate is acceptable for surveys (Hair *et al.*, 2011). Thus, by complying

with the recommended suggestions, the available 134 responses (89percent) qualify the required sample size

As stated in the preceding chapter, this study used PLS Structural Equation Modelling (SEM) to calculate its

Variable	Mean	Median	Observed Min	Observed Max	Excess Kurtosis	Skewness	Number of Observations Used	Cramér-von Mises Test Statistic	Cramér-von Mises p-value
BC	3.1	3	2	4	-0.694	0.182	134	0.19	0.007
RFID	3.8	4	1	5	-0.631	0.063	134	0.14	0.032
SS	4	4	2	5	-0.833	-0.081	134	0.255	0.001
SSCP	3.5	3	2	5	-0.624	0.145	134	0.276	0.001

to further conduct regression analysis.

Table 4.2 Descriptive Statistics for the Study Variables

Source: Smart PLS Output, 2025

Based on the descriptive analysis of the constructs presented in Table 4. 2, the overall relationship between the Internet of Things (IoT) and sustainable supply chain practices among employees of pharmaceutical companies in Nigeria can be better understood. The findings indicate that the mean values for IoT dimensions range from 3.1 (barcodes) to 4.0 (smart sensors), suggesting varying degrees of adoption among employees. The highest mean value was recorded for smart sensors (4.0), followed by RFID (3.8), implying a stronger preference for these technologies, likely due to their perceived efficiency and reliability in supply chain management. Conversely, barcodes had the lowest mean value (3.1), indicating a relatively lower level of utilization compared to other IoT dimensions.

The median values align with these observations, ranging from 3 (barcodes and SSCP) to 4 (smart sensors and RFID), reinforcing the trend of higher adoption for smart sensors and RFID. The observed minimum and maximum values further highlight the variability in adoption, with barcodes ranging from 2 to 4 and RFID from 1 to 5. The excess kurtosis values, which range from -0.833 (smart sensors) to -0.624 (SSCP), suggest that the data distributions are relatively flat, while the skewness values indicate slight asymmetry in responses. The Cramér-von Mises test results, with p-values below 0.05, confirm that the data distributions deviate from normality.

These findings suggest that while IoT technologies are generally adopted within pharmaceutical companies, smart sensors and RFID are the most preferred, whereas barcodes and SSCP are the least utilized. Despite this, the continued implementation of barcodes and SSCP, as indicated by the observed values, suggests that they still play a significant role in supply chain processes within the industry.

theoretical model using the software application Smart PLS (Hair *et al.*, 2019). In PLS analysis, the first step is to evaluate the measurement model, or the outer model. The measurement model assessment includes defining reliability of individual item, reliability of internal consistency, convergent validity and validity of discriminant (Hair *et al.*, 2019).

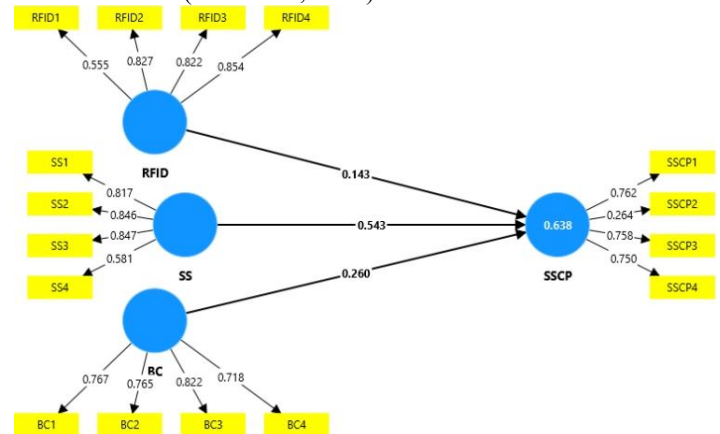


Figure 2: Initial Measurement Model

The figure 2 above shows the initial measurement model. It can be seen that not all the outer loadings of each variable's measure items meet up with the Hair *et al.* (2014) recommendation of 0.70 or above. Three items did not load up to 0.7, that is 1 measurement item of radio frequency identification (RFID1), 1 measurement item of smart sensors (SS4), and 1 measurement item of sustainable supply chain practice (SSCP2).

ASSESSMENT OF MEASUREMENT MODEL

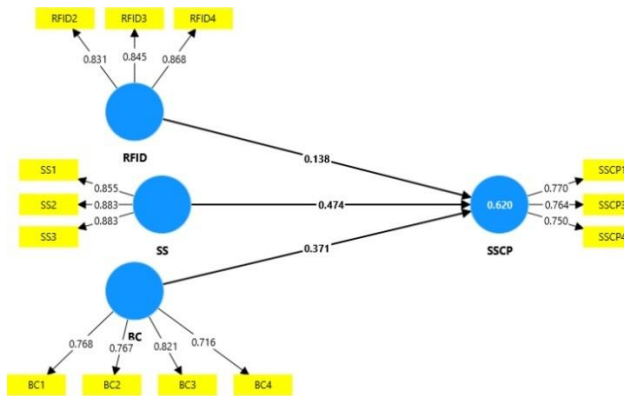


Figure 3: Modified Measurement Model

Table 4.3 Measurement Model: Reliability and Convergent Validity

Construct	Item	Loadings	AVE	CR
Sustainable supply chain practice	SSCP1	0.770	0.580	0.805
	SSCP3	0.764		
	SSCP4	0.750		
Smart sensors	SS1	0.855	0.764	0.906
	SS2	0.883		
	SS3	0.883		
Barcodes	BC1	0.768	0.591	0.852
	BC2	0.767		
	BC3	0.821		
	BC4	0.716		
Radio frequency identification	RFID2	0.831	0.719	0.885
	RFID3	0.845		
	RFID4	0.868		

Source: Smart PLS Output, 2025

MULTICOLLINEARITY TEST

Multicollinearity is a problem that occurs when the independent variables are extremely interrelated to as high as 0.9 and above (Tabachnick & Fidell, 2007). For this study Multicollinearity test was conducted using correlation matrixes for the independent variables, tolerance values and variance inflation factors (VIF). According to Hair et al., (2014), a tolerance level of 0.20 and below or a VIF value of 5 and above indicates the presence of multicollinearity among variables.

Table 4.4 Multicollinearity Test: Tolerance and

Exogenous Variables	Collinearity Statistics	
	Tolerance	VIF
Radio frequency identification	0.443	1.434
Smart sensors	0.327	1.475
Barcodes	0.326	1.731

VIF (n=134)

Source: Smart PLS Output, 2025

From the Table 4.4 it clearly shows that tolerance ranges between 0.327 – 0.443 considerably > 0.20. Similarly, VIF ranges from 1.434 – 1.731, and, thus, is good enough as being < 5. Consequently, it is concluded that there is no multicollinearity problem among the exogenous variables.

ASSESSMENT OF THE STRUCTURAL MODEL

Having confirmed that this study’s measurement models (inner model) are reliable and valid, this section evaluated the structural model. This research

The figure 3 above shows the modified measurement model. It can be seen that all the outer loadings of each variable’s measure items meet up with the Hair et al. (2011) recommendation of 0.70 or above.

INDIVIDUAL ITEM RELIABILITY

The first criterion for the reflective measurement model is the assessment of individual item reliability which is usually measured by assessing the outer loadings of each variable’s measure (Hair et al., 2019). Based on Hair et al. (2019) rule of thumb, an indicator with 0.70 outer loading is reliable and acceptable for previously developed scale.

Table 4.3 and Figure 3 illustrate that after the removal of three items with outer loading values below 0.70, the remaining items met the recommended threshold. Following the guidelines of Hulland (1999) and Hair et al. (2011), which suggest removing items that significantly impact composite reliability and average variance extracted (AVE), only three items with loadings below 0.70 were eliminated. As a result, 13 items were retained for further analysis, ensuring a more robust measurement model (refer to Figure 3 above and Table 4.3 below).

used the standard bootstrapping technique with a number of 5000 bootstrap samples and 134 cases to evaluate significance of the path coefficients (Hair *et al.*, 2019). The structural model of this study is composed of four latent constructs, namely; radio frequency identification, smart sensors and barcodes as independent variables and sustainable supply chain practice as the dependent variable (see Figure 4). The structural model usually confirms the level to which the empirical data collected support the existing theories (Hair *et al.*, 2014). That is, its evaluation is mainly used to determine the explanatory power of the research model and to test the developed hypotheses. Hair *et al.* (2014) recommended that the structural model can be generally assessed through test for collinearity issues, significance of relationships among the constructs, evaluation of the R^2 , effect sizes and assessment of the predictive relevance Q^2 . Notably, the key assessment tests of the structural model are the R^2 values of endogenous constructs and the level and significance of the path coefficients.

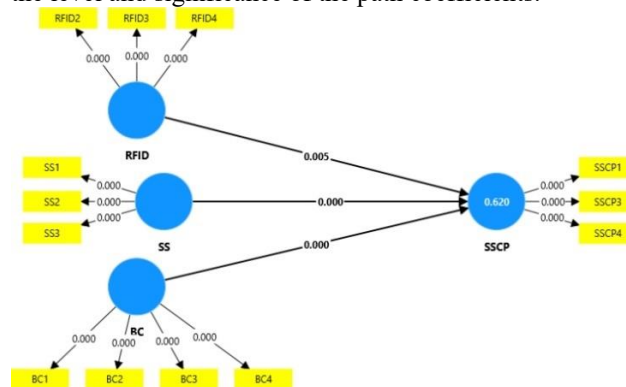


Figure 4: Bootstrapping (Direct Relationships)
Table 4.5 Structural Model: Test of Significance for

Direct Relationships

H ₀	Relationship	Beta	SE	T Statistics	P-Value	Statistically Significant	Decision
H ₀₁	RFID -> SSCP	0.138	0.049	2.834	0.005	Yes	Rejected
H ₀₂	SS -> SSCP	0.474	0.046	10.330	0.000	Yes	Rejected
H ₀₃	BC -> SSCP	0.371	0.054	6.851	0.000	Yes	Rejected

t- Value > 1.96; p-value < 0.05; RS = Radio frequency identification, SS = Smart sensors, CS = Barcodes, M and SP = Sustainable supply chain practice
Source: Smart PLS Output, 2025

The result of bootstrapping has shown that H₀₁, H₀₂ and H₀₃ are statistically significant and the relationship is positive. From the Table 4.5, the statistical analysis

has proved that the relationship between various Internet of Things (IoT) dimensions: Radio Frequency Identification (RFID), Smart Sensors (SS), and Barcodes (BC); and Sustainable Supply Chain Practices (SSCP) among pharmaceutical companies in Kaduna. The findings reveal that RFID has a positive but weak influence on SSCP ($\beta = 0.138$,) and the $p = 0.005$, indicating that while RFID contributes to sustainability, its impact is relatively lower. On the other hand, Smart Sensors demonstrate a strong positive effect on SSCP ($\beta = 0.474$), and the $p = 0.000$, suggesting that their implementation significantly enhances sustainable supply chain practices. Similarly, Barcodes exhibit a moderate positive relationship with SSCP ($\beta = 0.371$), and the $p = 0.000$, confirming their importance in supporting sustainability efforts within the supply chain. The range of Beta values are 0.10 – 0.29 weak effect, 0.30 – 0.45 moderate effect and 0.46 - 0.50 and strong effect (Latan *et al.*, 2023).

Overall, the results indicate that all three IoT components RFID, Smart Sensors, and Barcodes—play a crucial role in fostering sustainable supply chain practices among pharmaceutical firms in Nigeria. However, Smart Sensors have the most substantial influence, followed by Barcodes and then RFID. This suggests that while IoT technologies collectively contribute to sustainability, pharmaceutical companies may benefit most from prioritizing Smart Sensor adoption to achieve enhanced supply chain efficiency and sustainability. In summary, all the direct relationships between the independent variables and dependent variable are all significant based on the statistical data of this study and all the three null hypotheses were rejected, this means we accept the statement that there is a significant relationship between the independent variables and dependent variable.

REGRESSION FOR DIRECT RELATIONSHIPS

Table 4.6 Regression R² for Direct Relationships

	R-square	R-square adjusted
SSCP	0.620	0.614

Source: Smart PLS Output, 2025

The R-square (0.620) value indicates that 62% of the variation in Sustainable Supply Chain Practices

(SSCP) among pharmaceutical companies in Nigeria can be explained by the three Internet of Things (IoT) dimensions RFID, Smart Sensors, and Barcodes. This suggests a strong predictive power of the model, meaning these IoT components significantly contribute to sustainability in supply chain management.

Also, the table 4.6 equally shows that the Adjusted R-square (0.614) accounts for the number of predictors in the model and provides a more accurate estimate of its explanatory power. With an adjusted R-square of 0.614, it confirms that after adjusting for the number of independent variables, 61.4% of the variance in SSCP is still explained by the IoT dimensions. This minimal difference between R-square and adjusted R-square indicates that the model is robust, with little risk of over fitting.

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

The primary objective of this study is to investigate the role of internet of things on sustainable supply chain practice in pharmaceutical companies in Kaduna. The empirical findings supported all the hypotheses developed; thereby answering all the research questions and also supported the key theoretical positions upon which this study has been drawn. The study therefore concludes that there is a positive and significant effect that smart sensors, radio frequency identification and barcode has on sustainable supply chain practices in pharmaceutical companies. This equally implies that internet of things will affect sustainable supply chain practice positively.

Based on the findings, the following recommendations are made:

- i. Based on this finding, this study recommends that employees of pharmaceutical companies should integrate actively smart sensors and radio frequency identification digital technologies. This will help them to easily enhanced sustainable supply chain practice for operational efficiency and enhanced traceability which will help in identifying counterfeit medicines and effective performance of their organizations.
- ii. Barcodes were found to have significant positive effect on sustainable supply chain practice in pharmaceutical companies in Kaduna. Based on this finding, this study recommends that employees of pharmaceutical companies should engaged actively in barcodes. This will help them to have good inventory management which will easily enhanced sustainable supply chain practice, as shortages and scarcity are

handled and in turn increase performance of their organizations.

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