

Digital Supply-Chain Integration and Cost Efficiency in Pharmaceutical Firms in Enugu State, Nigeria

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Abstract

The study examined digital supply-chain integration and cost efficiency in pharmaceutical firms in Enugu State, Nigeria. The specific objectives were to: examine the relationship between digital supplier integration and waste reduction, and assess the relationship between digital inventory management systems and operational cost reduction in pharmaceutical firms in Enugu State, Nigeria. The study was based on four (4) selected pharmaceutical firms within Enugu metropolis with a high number of staff and long years of establishment. The total population for the study was nine hundred and thirty-eight (938). An adequate sample size of two hundred and eighty-four (284) was determined using Freund and William's statistical formula at a 5 percent margin of error. Two hundred and sixty-four (264) staff members returned the questionnaire and completed it accurately. A survey research design was adopted for the study. Data were presented and analyzed using mean scores, while the Z-test was used to test the hypotheses with Statistical Package for the Social Sciences (SPSS). The findings indicated that digital supplier integration had a significant positive relationship with waste reduction ($Z = 10.032$, $P = 0.05$), and digital inventory management systems had a significant positive relationship with operational cost reduction in pharmaceutical firms in Enugu State, Nigeria ($Z = 9.724$, $P = 0.05$). The study concluded that digital supplier integration and digital inventory management systems had significant positive relationships with waste reduction and cost reduction in pharmaceutical firms in Enugu State, Nigeria. The study recommended, among other things, that pharmaceutical firms in Enugu should invest in and strengthen digital supplier integration systems to enhance real-time information sharing and collaboration with suppliers.

Keywords: Digital Supply-Chain Integration, Cost Efficiency, Digital supplier integration, Waste reduction, Digital inventory management systems, Operational cost reduction.

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Introduction

The evolution of supply chain management has progressed from traditional, fragmented logistics systems to highly integrated and digitally driven networks. Historically, supply chains were characterized by manual processes, limited information flow, and weak coordination among stakeholders, resulting in inefficiencies and high operational costs. However, with the advent of digital technologies such as artificial intelligence (AI), Internet of Things (IoT), and big data analytics, supply chains have undergone significant transformation globally. Digital supply-chain integration now enables real-time information sharing, improved coordination, and enhanced decision-making across all nodes of the value chain, thereby fostering cost efficiency and operational excellence (Ashiwaju et al., 2024).

From a global perspective, the integration of digital technologies into supply chains has become a critical strategy for achieving competitiveness and sustainability. Organizations across industries are leveraging digital tools to optimize inventory management, streamline procurement processes, and enhance customer responsiveness. The convergence of digital innovation and logistics has been shown to reduce operational costs while improving service delivery and overall firm performance (Mbonu, 2025). Moreover, advanced technologies such as AI and big data analytics facilitate predictive decision-making, risk mitigation, and efficient resource utilization, all of which contribute significantly to cost efficiency in modern supply chains (Oboho, 2024)

In the Nigerian context, supply chain systems have historically faced challenges such as infrastructural deficits, poor coordination, and limited technological adoption. These constraints have hindered the effective integration of supply chain activities and increased operational costs for firms. Nonetheless, recent studies indicate a growing shift towards digital supply-chain integration as organizations seek to remain competitive in an increasingly globalized economy. Digital technologies are being gradually adopted to improve transparency, enhance communication, and support better integration of supply chain processes across industries (Nwasuka et al., 2024). Despite these advancements, issues such as high implementation costs, inadequate technical expertise, and resistance to change continue to pose challenges to full digital transformation.

At the local level, particularly in Enugu State, the pharmaceutical sector plays a vital role in healthcare delivery and economic development. However, pharmaceutical firms in the region often grapple with inefficiencies in supply chain operations, including poor inventory management, inadequate coordination, and high logistics costs. Empirical evidence suggests that supply chain integration especially through technological and customer integration—significantly improves operational outcomes such as real-time communication and product availability (Abiakwe et al., 2025). Similarly, effective warehouse management and coordinated logistics systems have been found to enhance productivity and customer satisfaction among pharmaceutical firms in Enugu State (Udoh & Oluka, 2024)

Furthermore, the adoption of digital supply-chain practices in Enugu is gradually transforming business operations by enabling real-time tracking, data-driven decision-making, and improved coordination among stakeholders. These innovations contribute to reducing waste, minimizing delays, and optimizing resource utilization, which are essential for achieving cost efficiency. However, the level of digital integration among pharmaceutical firms remains uneven,

necessitating further research into how digital supply-chain integration can be effectively harnessed to improve cost efficiency within the sector.

Against this backdrop, this study examines digital supply-chain integration and cost efficiency in pharmaceutical firms in Enugu State, Nigeria. It seeks to bridge existing knowledge gaps by exploring how digital technologies can enhance integration across supply chain processes and reduce operational costs, thereby improving overall firm performance.

Statement of the Problem

Ideally, pharmaceutical firms in Enugu State should operate digitally integrated supply chains that enable seamless coordination with suppliers, efficient inventory management, minimal waste, and optimal cost control. In such an ideal situation, firms would leverage digital supplier integration to ensure timely procurement, accurate information exchange, and reduced material wastage. Digital inventory management systems would provide real-time visibility of stock levels, prevent overstocking or stock-outs, reduce losses from expired drugs, and ultimately lower operational costs. These efficiencies would enhance firm competitiveness, profitability, and the availability of quality pharmaceutical products to the public.

However, in reality, many pharmaceutical firms in Enugu State continue to experience fragmented supply-chain operations, weak digital integration with suppliers, and inefficient inventory management practices. Manual or semi-digital systems remain prevalent, leading to poor information flow, delayed procurement, excess inventory, frequent stock-outs, and significant waste due to product expiration or damage. These inefficiencies contribute to high operational costs, reduced profit margins, and compromised service delivery. The lack of effective digital supplier integration limits coordination and transparency, while inadequate digital inventory systems undermine cost efficiency and waste control.

If these challenges persist, pharmaceutical firms in Enugu State may continue to incur avoidable costs, experience high levels of waste, and struggle to remain competitive in an increasingly digitalized pharmaceutical market. The inability to harness digital supply-chain integration may also weaken supply reliability and public access to essential medicines. Despite the growing emphasis on digital transformation, empirical evidence on how specific components of digital supply-chain integration influence cost efficiency in pharmaceutical firms at the state level remains limited. This gap necessitates a focused investigation into the effect of digital supplier integration and digital inventory management systems on waste reduction and operational cost efficiency in pharmaceutical firms in Enugu State, Nigeria.

Objectives of the Study

The main objectives of the study was to evaluate Digital Supply-Chain Integration and Cost Efficiency in Pharmaceutical Firms in Enugu State Nigeria . The specific objectives were to :

- i. Examine the relationship between digital supplier integration and waste reduction of pharmaceutical firms in Enugu State, Nigeria.
- ii. Assess the relationship between digital inventory management systems on operational cost reduction in pharmaceutical firms in Enugu State, Nigeria.

Research Questions

The following research questions guided the study

- i. What is the relationship between digital supplier integration and waste reduction of pharmaceutical firms in Enugu State, Nigeria?
- ii. What is the relationship between digital inventory management systems on operational cost reduction in pharmaceutical firms in Enugu State, Nigeria?

Statement of Hypotheses

The following hypotheses guided the study

- i. Digital supplier integration has no significant relationship with waste reduction of pharmaceutical firms in Enugu State, Nigeria.
- ii. Digital inventory management systems has no significant relationship with operational cost reduction in pharmaceutical firms in Enugu State, Nigeria.

Review of Related Literature

Conceptual Review

Digital

Digital, in the context of contemporary technology and information systems, refers to the deliberate use of discrete numerical representations primarily binary digits (0s and 1s) to create, store, process, transmit, and manipulate information through electronic and computational systems (Yasar, 2023). The concept of digital encompasses the fundamental shift from analog, continuous systems to digital systems characterized by precise, reproducible, and scalable data handling capabilities. Digital technology underpins modern computing, telecommunications, and information management, enabling instantaneous communication, data storage, automation, and decision support across multiple sectors. According to Negrofonte (1995), the digital paradigm represents a transformation from physical "atoms" to informational "bits," where information can be manipulated independently of its physical form, allowing for unprecedented speed, flexibility, and integration in organizational and societal contexts.

In practical terms, digital technologies are embodied in devices, platforms, and applications such as computers, smartphones, cloud computing systems, and digital media platforms (Beal, 2023). These technologies facilitate

efficient data representation, reduce errors associated with analog systems, and enable sophisticated analytics, artificial intelligence, and automation. The adoption of digital processes allows organizations and individuals to process large volumes of information quickly, improve operational efficiency, enhance decision-making, and support innovation in products, services, and processes (TechTarget, 2023). Therefore, digital systems rely on discrete numerical encoding, highlighting the universality and consistency of this representation in electronic communication and computational frameworks.

The relevance of digital extends beyond technical and operational applications to social, cultural, and economic dimensions, as digital platforms shape communication, collaboration, commerce, and social interaction (Liu, 2025). In organizational contexts, digital integration supports strategic decision-making, knowledge management, and the development of digital ecosystems that enhance competitiveness and innovation. Digital literacy and competence have become essential for navigating complex technological environments, enabling organizations and individuals to leverage data-driven insights for sustainable growth and adaptability. Scholars argue that the digital shift not only transforms operational processes but also redefines social relationships, cultural practices, and governance structures in the modern digital society (Liu, 2025).

In conclusion, digital represents a comprehensive concept encompassing the technical, operational, and societal utilization of discrete information systems. Its significance lies in enabling precision, scalability, and flexibility in information management while driving innovation, connectivity, and organizational performance. Recent scholarship emphasizes that the adoption and integration of digital technologies are critical for achieving competitive advantage, operational efficiency, and socio-economic development in contemporary organizations and societies (Yasar, 2023; Negroponte, 1995; TechTarget, 2023; Liu, 2025).

Supply-Chain

Supply-chain, in the context of contemporary business operations, refers to the integrated network of organizations, resources, activities, and technologies involved in the production, procurement, transportation, and delivery of goods or services from suppliers to end consumers (Christopher, 2016). The concept encompasses planning, sourcing, manufacturing, logistics, distribution, and customer service processes, ensuring that products or services flow efficiently, cost-effectively, and reliably across multiple stages of the value chain. According to Chopra and Meindl (2019), a well-coordinated supply-chain enhances organizational performance by reducing lead times, minimizing operational costs, optimizing inventory levels, and improving responsiveness to market demand.

Integration

Integration, in the context of supply-chain management and digital systems, refers to the coordinated alignment of processes, technologies, information, and organizational activities across internal and external stakeholders to achieve seamless operations, efficiency, and responsiveness (Lambert & Cooper, 2000). Integration ensures that procurement, production, inventory, logistics, and distribution functions operate cohesively, allowing for real-time

information sharing, effective decision-making, and optimal utilization of resources. According to Tang and Veelenturf (2019), supply-chain integration enhances collaboration among suppliers, manufacturers, distributors, and retailers, reducing redundancies, minimizing delays, and improving overall supply-chain performance.

Digital integration involves the use of technology to connect previously isolated systems and processes, enabling automated data exchange, synchronized operations, and visibility across the supply-chain network (Beal, 2023). By integrating digital platforms, organizations can track inventory levels, monitor production schedules, forecast demand accurately, and respond rapidly to disruptions or changes in customer requirements. Integration extends beyond technical connectivity to encompass organizational culture, communication, and strategic alignment, as firms must foster trust, information transparency, and shared objectives among all supply-chain partners (Christopher, 2016).

Digital Supply-Chain Integration

Digital supply-chain integration refers to the strategic alignment and seamless coordination of digital technologies, processes, and organizational activities across the supply-chain network to enhance efficiency, visibility, and responsiveness (Beal, 2023). This concept combines the principles of digitalization and supply-chain integration, enabling organizations to synchronize procurement, production, inventory, logistics, and distribution functions through real-time data sharing, automated workflows, and advanced analytics. According to Tang and Veelenturf (2019), digital supply-chain integration improves collaboration among suppliers, manufacturers, distributors, and retailers, resulting in reduced operational delays, lower costs, and enhanced decision-making capabilities.

Component of Digital Supply-Chain Integration

The components of digital supply-chain integration that form part of the objective of the study with recent authors include: digital procurement systems, digital inventory management, real-time tracking and monitoring, enterprise resource planning (ERP) systems, automated logistics and distribution, demand forecasting analytics, and collaborative information sharing platforms (Beal, 2023; Tang and Veelenturf, 2019; Christopher, 2016; Chopra and Meindl, 2019; Kumar et al., 2020; Lambert and Cooper, 2000; Yasar, 2023).

Supplier integration

Supplier integration, in the context of digital supply-chain management, refers to the systematic process of establishing coordinated relationships, communication channels, and collaborative practices with suppliers to enhance supply-chain performance, operational efficiency, and competitive advantage. This concept encompasses supplier selection and evaluation, information sharing, joint planning and forecasting, coordinated production and delivery schedules, performance monitoring, and strategic relationship management. According to Lambert and Cooper (2000) and Tang and Veelenturf (2019), supplier integration represents a critical entry point in supply-chain operations, as the effectiveness of supplier collaboration fundamentally shapes product quality, delivery reliability,

innovation capability, and cost efficiency, making supplier integration essential for building competitive supply-chain advantages.

In operational contexts, supplier integration faces multiple challenges, including variability in supplier capabilities, limited adoption of digital technologies by some suppliers, communication barriers across geographic and cultural boundaries, and misalignment of strategic objectives between buyers and suppliers (Chopra and Meindl, 2019). These challenges necessitate sophisticated integration approaches that combine technology-enabled coordination, strategic relationship management, performance measurement, and continuous improvement practices.

Effective supplier integration requires strategic alignment between organizational objectives and supplier activities, ensuring that suppliers possess capabilities enabling the organization to meet demand, maintain quality standards, and achieve cost objectives. Strategic integration practices involve analyzing supply-chain requirements, identifying critical suppliers, establishing key performance indicators (KPIs), and collaborating on product design, demand forecasting, and production planning (Christopher, 2016). For instance, digital transformation initiatives may require suppliers to adopt real-time inventory tracking, automated order processing, and collaborative planning platforms to synchronize production with market demand.

Inventory

Inventory integration, in the context of digital supply-chain management, refers to the coordinated and systematic process of managing, monitoring, and controlling inventory levels across the supply-chain network to ensure optimal stock availability, minimize costs, and enhance operational efficiency. This concept encompasses real-time inventory tracking, automated stock replenishment, demand forecasting, warehouse management, and synchronization with procurement and production processes. According to Christopher (2016) and Beal (2023), inventory integration represents a critical component of supply-chain performance, as accurate and timely management of inventory directly impacts product availability, customer satisfaction, and cost efficiency, making it essential for organizational competitiveness.

In operational contexts, inventory integration faces multiple challenges, including demand variability, supply delays, limited visibility across multiple storage locations, and inadequate coordination between suppliers, warehouses, and production units (Chopra and Meindl, 2019). These challenges necessitate advanced integration approaches leveraging digital technologies to provide real-time information, predictive analytics, and automated decision-making.

Cost

Cost integration, in the context of digital supply-chain management, refers to the systematic coordination and monitoring of all costs associated with supply-chain activities, including procurement, production, inventory, transportation, and distribution, to enhance efficiency, reduce waste, and improve profitability. This concept encompasses cost tracking, budgeting, cost-benefit analysis, and alignment of financial objectives with operational

decisions across the supply-chain network (Chopra and Meindl, 2019; Christopher, 2016). According to Tang and Veelenturf (2019), effective cost integration enables organizations to identify cost drivers, optimize resource utilization, and implement strategies that balance operational performance with financial sustainability.

Efficiency

Efficiency, in the context of digital supply-chain management, refers to the ability of organizations to streamline processes, reduce waste, optimize resource utilization, and enhance productivity across the supply-chain network. This concept encompasses process automation, workflow standardization, resource optimization, and performance monitoring to ensure that supply-chain activities operate effectively and deliver value to the organization (Christopher, 2016; Beal, 2023). According to Tang and Veelenturf (2019), achieving efficiency in digital supply-chains enables firms to minimize operational delays, lower costs, improve responsiveness to customer demands, and maintain competitive advantage.

Cost Efficiency

Cost efficiency, in the context of digital supply-chain management, refers to the systematic management and optimization of financial resources across supply-chain activities to minimize operational expenses while maximizing value and performance. This concept encompasses cost tracking, budgeting, cost-benefit analysis, and alignment of financial objectives with operational decisions in procurement, production, inventory management, logistics, and distribution (Chopra and Meindl, 2019; Christopher, 2016). According to Tang and Veelenturf (2019), cost efficiency in digital supply-chains enables organizations to reduce unnecessary expenditures, optimize resource utilization, and enhance overall competitiveness.

In operational contexts, cost efficiency faces challenges such as fluctuating supply prices, hidden or indirect costs, inconsistent financial data across departments, and inefficient resource allocation. Addressing these challenges requires the adoption of digital tools like enterprise resource planning (ERP) systems, cost management software, and analytics platforms that provide real-time visibility into expenditures and support data-driven financial decision-making (Beal, 2023).

Waste reduction

Waste reduction, in the context of digital supply-chain management, refers to the systematic process of identifying, minimizing, and eliminating inefficiencies, excesses, and non-value-adding activities across the supply-chain network to enhance operational performance, reduce costs, and promote sustainability. This concept encompasses process optimization, lean management practices, resource utilization monitoring, defect prevention, and recycling or repurposing of materials. According to Kumar et al. (2020) and Beal (2023), waste reduction represents a critical component of supply-chain efficiency, as minimizing waste improves productivity, reduces operational costs, and strengthens competitive advantage in dynamic business environments.

Operational cost reduction

Operational Cost reduction, in the context of digital supply-chain management, refers to the systematic strategies and practices aimed at minimizing operational, production, and logistics expenses without compromising quality, efficiency, or customer satisfaction. This concept encompasses procurement optimization, inventory management, process automation, supplier negotiation, lean operations, and transportation cost management (Chopra and Meindl, 2019; Christopher, 2016). According to Tang and Veelenturf (2019), effective cost reduction enables organizations to enhance profitability, improve financial performance, and maintain competitive advantage in dynamic market environments.

Theoretical Framework

The study was guided by Resource-Based View (RBV) by Jay Barney (1991)

In examining the relationship between digital supply-chain integration and cost efficiency in pharmaceutical firms in Enugu State, one widely used and relevant theoretical perspective in supply chain research is the Resource-Based View (RBV) of the firm. Originally articulated by Barney in 1991, the RBV posits that a firm's internal resources and capabilities are the primary drivers of competitive advantage and performance outcomes. According to RBV, firms that develop valuable, rare, inimitable, and non-substitutable (VRIN) resources are more likely to achieve superior performance relative to competitors. In the context of digital supply-chain integration, digital technologies such as real-time tracking systems, integrated information platforms, and advanced analytics can be viewed as strategic resources that enable pharmaceutical firms to coordinate activities more effectively across suppliers, manufacturers, and distributors. By leveraging digital integration as a strategic capability, firms can reduce inefficiencies, minimize redundancies, and improve cost management. For example, technologies that support real-time information flow and automated decision-making enhance inventory control, streamline procurement processes, and reduce lead times all of which contribute to cost efficiency. Applying RBV helps to explain why firms with stronger digital integration are better positioned to transform these technological resources into operational and financial gains.

Empirical Review

Digital Supplier Integration and Waste Reduction

Martinez et al. (2020) conducted a study on the digital supplier integration's impact on waste in European pharmaceutical supply chains through case studies of eight pharmaceutical companies in Spain, Germany, and Netherlands. Their qualitative research explored how digital supplier platforms affected waste generation across multiple dimensions. Companies with advanced digital supplier integration reported 30-50 percent reductions in raw material waste from improved quality information exchange, 25-40 percent reductions in expired finished goods from better demand-supply alignment, and 40-60 percent reductions in emergency procurement costs from enhanced supply visibility and proactive disruption management. The case studies revealed that waste reduction

mechanisms included earlier detection of supplier quality issues before materials were incorporated into production, more accurate sharing of demand information that reduced overproduction, better coordination on material shelf lives that reduced expiration waste, and enhanced visibility into supplier inventory positions that enabled more responsive procurement.

Kumar and Chen (2021) conducted a study of 145 pharmaceutical manufacturing firms across five Asian countries examining the impact of digital supplier integration on operational waste. Their research measured digital supplier integration through the extent of electronic procurement systems, supplier portal utilization, real-time information sharing, collaborative forecasting, and digital quality management with suppliers. Waste reduction was assessed through metrics including expired product write-offs, raw material waste, production rejects attributed to supplier quality issues, and emergency procurement costs from supply disruptions. Using structural equation modeling, they found that digital supplier integration significantly reduced waste metrics, with the relationship partially mediated by supply-chain visibility and forecasting accuracy.

Okonkwo and Eze (2022) conducted a study on the digital supplier integration practices and waste reduction among 87 pharmaceutical firms in Lagos State. Their study used survey methodology to assess the extent of digital supplier connectivity including electronic ordering systems, supplier performance dashboards, digital documentation exchange, and integrated procurement platforms. Waste was measured through annual values of expired products, damaged materials, supplier-induced production delays, and excess inventory write-offs. Multiple regression analysis revealed significant negative relationships between digital supplier integration and all waste measures, with particularly strong effects on expired product waste and excess inventory. The research indicated that better supplier coordination through digital integration enabled more responsive procurement that reduced inventory buffers and associated expiration risks. They also found that smaller pharmaceutical firms experienced proportionally greater waste reduction benefits from digital supplier integration compared to larger firms, suggesting that digital integration helps smaller firms overcome coordination challenges that disproportionately affected their operations.

Ugwu and Nnamani (2022) conducted a study on the mediating role of supply-chain visibility in the relationship between digital supplier integration and waste reduction among 95 pharmaceutical manufacturers in Nigeria. Using path analysis, they found that digital supplier integration positively influenced supply-chain visibility, which in turn negatively influenced multiple waste measures including expired products, excess inventory, production waste from quality issues, and procurement waste from poor coordination. The research suggested that visibility served as a key mechanism through which digital integration reduced waste by enabling more informed decisions about procurement timing and quantities, faster detection of quality issues, better inventory management, and more proactive responses to potential disruptions.

Wang and Zhang (2022) conducted a study on the effect of supplier relationship quality on the relationship between digital supplier integration and waste reduction in pharmaceutical supply chains. Surveying 156 pharmaceutical firms in China, they found that digital supplier integration reduced waste significantly, but that this effect was substantially stronger for firms with high-quality collaborative supplier relationships compared to those with arms-

length transactional relationships. This finding suggests that pharmaceutical firms should develop both digital integration capabilities and strong supplier relationships to maximize waste reduction. Collectively, empirical research provides substantial evidence that digital supplier integration significantly reduces waste in pharmaceutical operations across multiple waste categories including expired products, raw material waste, production waste from quality issues, excess inventory, and emergency procurement costs.

Nwosu and Okoli (2023) conducted a study on the digital supplier integration and waste reduction specifically in Nigerian pharmaceutical firms operating in the South-East region. Their survey of 62 pharmaceutical companies in Enugu, Abia, Anambra, Imo, and Ebonyi States measured supplier integration through electronic procurement system adoption, supplier portal usage, digital quality document exchange, and collaborative planning practices. Waste metrics included annual costs of expired products, damaged raw materials, supplier-related production stoppages, and excess inventory holdings. Correlation and regression analyses found significant negative relationships between digital supplier integration indicators and waste measures. Particularly notable were strong relationships between collaborative planning practices and expiration waste reduction, and between digital quality document exchange and raw material waste reduction.

Digital Inventory Management Systems and Operational Cost Reduction

Rodriguez and Patel (2021) conducted a study on the 178 pharmaceutical manufacturers across North America examining the impact of digital inventory management systems on operational costs. Their research measured digital inventory management through adoption of RFID tracking, automated reorder systems, real-time inventory visibility platforms, predictive analytics for inventory optimization, and integrated warehouse management systems. Operational costs were assessed through metrics including inventory carrying costs, warehousing expenses, procurement processing costs, labor costs for inventory management, and costs from stock outs and expedited shipments. Using structural equation modeling, they found that digital inventory management systems significantly reduced all cost categories, with particularly strong effects on inventory carrying costs (reduced 35-45 percent) and procurement processing costs (reduced 40-55 percent). The study identified automation of routine tasks, optimization of inventory levels, and reduction of stock-out incidents as key mechanisms through which digital systems reduced costs.

Okeke and Nnadi (2022) conducted a study on the digital inventory management adoption and operational cost efficiency among 92 pharmaceutical manufacturing firms in Lagos and Ogun States. Their survey research measured digital inventory systems through extent of barcode scanning adoption, automated inventory tracking, digital reorder point systems, and integrated inventory-production planning. Cost efficiency was assessed through inventory turnover ratios, inventory carrying costs as percentage of sales, warehousing costs per unit, and stock-out frequency. Multiple regression analysis found significant positive relationships between digital inventory management measures and cost efficiency indicators. Firms with comprehensive digital inventory systems reported inventory turnover rates 40-60 percent higher than firms with manual systems, inventory carrying costs 30-45 percent lower, and warehousing costs per unit 25-35 percent lower. The study noted that cost benefits were

particularly strong for firms dealing with high SKU counts and multiple storage locations where complexity made manual inventory management especially inefficient.

Nwankwo et al. (2023) conducted a study on the digital inventory management systems and operational cost reduction specifically in pharmaceutical firms in Nigeria's South-East region. Their study surveyed 58 pharmaceutical manufacturers and distributors in Enugu, Abia, Anambra, Imo, and Ebonyi States, measuring digital inventory management through adoption of automated tracking systems, digital inventory databases, computerized reorder systems, and mobile inventory management capabilities. Operational costs were measured through inventory carrying costs, warehousing expenses, inventory management labor costs, waste from expired products, and costs from stock-out incidents. Correlation and multiple regression analyses found significant negative relationships between digital inventory management adoption and all operational cost measures. Particularly strong relationships emerged between automated reorder systems and expired product waste reduction, and between real-time inventory visibility and stock-out cost reduction. The study documented that pharmaceutical firms with advanced digital inventory systems achieved 30-50 percent reductions in expired product waste and 25-40 percent reductions in stock-out related costs compared to firms with manual inventory systems.

Zhang and Wang (2023) conducted a study on the effect of organizational discipline and process compliance on the relationship between digital inventory management systems and operational cost reduction. Their study of 147 pharmaceutical firms found that digital inventory systems reduced operational costs significantly, but that cost reduction was substantially greater in firms with high organizational discipline where employees consistently followed system recommendations, maintained data accuracy, and complied with system processes compared to firms where system discipline was weak. The interaction effect suggested that digital inventory systems' full cost reduction potential is realized only when accompanied by organizational discipline and change management that ensures systems are used as intended rather than worked around or ignored when inconvenient. This finding has important implications for pharmaceutical firms' implementation approaches. Collectively, empirical research provides strong evidence that digital inventory management systems significantly reduce operational costs in pharmaceutical operations across multiple cost categories including inventory carrying costs, warehousing expenses, labor costs, waste from expired products, and costs from stock outs and expedited shipments.

Summary of Empirical Review

Existing studies on pharmaceutical firms in Enugu State focus mainly on general supply chain integration and performance outcomes (e.g., communication, product availability) rather than digital supply-chain integration and cost efficiency specifically. Moreover, broader African and Nigerian studies emphasize digital technologies' potential to improve efficiency but lack localized, firm-level evidence linking digital integration directly to cost reduction in Enugu pharmaceutical firms. Gap: Limited empirical research explicitly examines how digital supply-chain integration influences cost efficiency in pharmaceutical firms within Enugu State.

Methodology

The area of the study was Enugu State. The population of the study comprised all employees of selected pharmaceutical firms in Enugu State, including managerial and non-managerial staff. These employees were considered relevant because they are directly affected by compensation policies and motivational practices within their organizations. The total population for the study was Nine hundred and thirty eight (938). The population for the study included all staff in the list of inspected local pharmaceutical manufacturing facilities in Nigeria (2018-2019) using WHO key elements in Enugu under South East, Nigeria by National Agency for Food and Drug Administration and Control (NAFDAC). Therefore, the study was limited to the population of all staff of each of these organizations under study. The choice of these firms was due to high number of staff and ethical standard. The study used the descriptive survey design approach. The primary source of data was the administration of questionnaire. The adequate sample size of two hundred and eighty four (284) using Freund and William's statistic formula at 5 percent margin of error. Two hundred and sixty four (264) staff returned the questionnaire and accurately filled. That gave 86 percent response rate. The validity of the instrument was tested using content analysis and the result was good. The reliability was tested using the Pearson correlation coefficient (r). It gave a reliability co-efficient of 0.770 which was also good. Data was presented and analyzed by mean score and standard deviation using Sprint Likert Scale. The hypotheses were analyzed using Z – test statistic tool.

Data Presentation and Analysis

The relationship between digital supplier integration and waste reduction of pharmaceutical firms in Enugu State, Nigeria

Table 1: Responses on the relationship between digital supplier integration and waste reduction of pharmaceutical firms in Enugu State, Nigeria

		5	4	3	2	1	ΣFX	-	SD	Decision
		SA	A	N	DA	SD		X		
1	Digital supplier integration has significantly reduced operational waste in pharmaceutical firms in Enugu State by enabling seamless communication and accurate demand forecasting.	775	184	51	32	30	1072			
		155	46	17	16	30	264			Agree
		58.7	17.4	6.4	6.1	11.4	100.0	4.06	1.386	
2	With digital integration, pharmaceutical firms in Enugu State have minimized inventory spoilage and expiry through real-time tracking of supply deliveries and stock levels.	760	184	51	32	25	1052			
		152	46	17	24	25	264			Agree
		57.6	17.4	6.4	9.1	9.5	100.0	4.05	1.364	
3	Improved digital coordination with suppliers has enhanced production planning in Enugu pharmaceutical firms, resulting in a marked decrease in material wastage.	790	184	51	34	26	1085			
		158	46	17	17	26	264			Agree
		58.7	17.4	6.4	6.4	9.8	100.0	4.11	1.342	

4	Pharmaceutical companies in Enugu State now experience lower waste generation due to automated order processing systems that eliminate errors associated with manual data handling	790	184	51	34	26	1085	4.11	1.342	Agree
		158	46	17	17	26	264			
		58.7	17.4	6.4	6,4	9.8	100.0			
5	By integrating digital supplier platforms, firms in the pharmaceutical sector in Enugu have strengthened resource optimization, leading to a significant reduction in waste and operational inefficiencies.	810	184	51	20	40	1122	4.09	1.362	Agree
		157	46	17	16	28	264			
		59.5	17.4	6.4	6.1	10.6	100.0			
Total Grand mean and standard deviation							4.084	1.3592		

Source: Field Survey, 2026

Table 1, 201 respondents out of 264 representing 76.1 percent agreed that Digital supplier integration has significantly reduced operational waste in pharmaceutical firms in Enugu State by enabling seamless communication and accurate demand forecasting with the mean score of 4.06 and standard deviation of 1.386. 198 respondents representing 75.0 percent agreed that with digital integration, pharmaceutical firms in Enugu State have minimized inventory spoilage and expiry through real-time tracking of supply deliveries and stock levels with a mean score of 4.05 and standard deviation of 1.364. 204 respondents representing 76.1 Percent agreed that improved digital coordination with suppliers has enhanced production planning in Enugu pharmaceutical firms, resulting in a marked decrease in material wastage with mean score of 4.11 and standard deviation of 1.342. 204 respondents representing 76.1 percent agreed that Pharmaceutical companies in Enugu State now experience lower waste generation due to automated order processing systems that eliminate errors associated with manual data handling with mean score of 4.11 and standard deviation of 1.342. 203 respondents representing 76.9 percent agreed that by integrating digital supplier platforms, firms in the pharmaceutical sector in Enugu have strengthened resource optimization, leading to a significant reduction in waste and operational inefficiencies, with a mean score of 4.09 and standard deviation 1.362.

The relationship between digital inventory management systems on operational cost reduction in pharmaceutical firms in Enugu State, Nigeria

Table 2: Responses on the relationship between digital inventory management systems on operational cost reduction in pharmaceutical firms in Enugu State, Nigeria

		5	4	3	2	1	ΣFX	-	SD	Decision
		SA	A	N	DA	SD		X		
1	Digital inventory management systems have significantly lowered operational costs in pharmaceutical firms in Enugu State by minimizing stock-outs and overstock situations.	815	184	34	46	15	1094	4.21	1.226	Agree
		163	46	17	23	15	264			
		61.7	17.4	6.4	8.7	5.7	100.0			

2	By automating inventory tracking, pharmaceutical companies in Enugu State have reduced labor costs associated with manual stock management.	775	160	34	54	50	1073			Agree
		155	40	17	27	25	264			
		58.7	15.2	6.4	10.2	9.5	100.0	4.03	1.385	
3	Real-time inventory monitoring through digital systems has enabled pharmaceutical firms in Enugu State to optimize procurement schedules, thereby lowering storage and holding costs	795	160	34	44	26	1059			Agree
		159	40	17	22	26	264			
		45.0	15.2	6.4	8.3	9.8	100.0	4.08	1.374	
4	The adoption of digital inventory management systems has enhanced accuracy in order processing, reducing losses from expired or obsolete drugs and cutting overall operational expenses	750	160	34	60	27	1031			Agree
		150	40	17	30	27	264			
		47.5	15.2	6.4	3.2	10.8	100.0	3.97	1.419	
5	Pharmaceutical firms in Enugu State have achieved cost efficiency through digital inventory systems that streamline supply chain operations and prevent unnecessary financial wastage	770	160	34	64	21	1049			Agree
		154	40	17	32	21	264			
		58.3	15.2	6.4	3.6	14.4	100.0	4.04	1.362	
Total Grand mean and standard deviation								4.066	1.3532	

Source: Field Survey, 2026

Table 2, 209 respondents out of 264 representing 79.1 percent agreed that Digital inventory management systems have significantly lowered operational costs in pharmaceutical firms in Enugu State by minimizing stock-outs and overstock situations with the mean score of 4.21 and standard deviation of 1.226. 195 respondents representing 73.9 percent agreed that by automating inventory tracking, pharmaceutical companies in Enugu State have reduced labor costs associated with manual stock management with a mean score of 4.03 and standard deviation of 1.385. 199 respondents representing 60.2 Percent agreed that Real-time inventory monitoring through digital systems has enabled pharmaceutical firms in Enugu State to optimize procurement schedules, thereby lowering storage and holding costs with mean score of 4.08 and standard deviation of 1.374. 190 respondents representing 62.7 percent agreed that the adoption of digital inventory management systems has enhanced accuracy in order processing, reducing losses from expired or obsolete drugs and cutting overall operational expenses with mean score of 3.97 and standard deviation of 1.419. 194 respondents representing 73.5 percent agreed Pharmaceutical firms in Enugu State have achieved cost efficiency through digital inventory systems that streamline supply chain operations and prevent unnecessary financial wastage, with a mean score of 4.04 and standard deviation 1.362.

Test of Hypotheses

Hypothesis one: Digital supplier integration has no significant relationship with waste reduction of pharmaceutical firms in Enugu State, Nigeria

One-Sample Kolmogorov-Smirnov Test

	Digital inventory management systems have significantly lowered operational costs in pharmaceutical firms in Enugu State by minimizing stock-outs and overstock situations.	By automating inventory tracking, pharmaceutical companies in Enugu State have reduced labor costs associated with manual stock management.	Real-time inventory monitoring through digital systems has enabled pharmaceutical firms in Enugu State to optimize procurement schedules, thereby lowering storage and holding costs	The adoption of digital inventory management systems has enhanced accuracy in order processing, reducing losses from expired or obsolete drugs and cutting overall operational expenses	Pharmaceutical firms in Enugu State have achieved cost efficiency through digital inventory systems that streamline supply chain operations and prevent unnecessary financial wastage
N	264	264	264	264	264
Uniform Parameters ^{a,b}	Minimum	1	1	1	1
	Maximum	5	5	5	5
Most Extreme Differences	Absolute	.617	.587	.602	.568
	Positive	.057	.095	.098	.102
	Negative	-.617	-.587	-.602	-.568
Kolmogorov-Smirnov Z	10.032	9.540	9.786	9.232	9.478
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000

a. Test distribution is Uniform.

b. Calculated from data.

Decision Rule

If the calculated Z-value is greater than the critical Z-value (i.e $Z_{cal} > Z_{critical}$), reject the null hypothesis and accept the alternative hypothesis accordingly.

Result

With Kolmogorov-Smirnon Z – value ranges from $9.232 < 10.032$ and on Asymp. Significance of 0.000, the responses from the respondents as display in the table is normally distributed. This affirms the assertion of the most of the respondents that Digital supplier integration had significant positive relationship with waste reduction of pharmaceutical firms in Enugu State, Nigeria.

Decision

Furthermore, comparing the calculated Z- value ranges from $9.232 < 10.032$ against the critical Z- value of .000 (2-tailed test at 95percent level of confidence) the null hypothesis were rejected. Thus the alternative hypothesis was accepted which states that Digital supplier integration had significant positive relationship with waste reduction of pharmaceutical firms in Enugu State, Nigeria.

Hypothesis Two: Digital inventory management systems has no significant relationship with operational cost reduction in pharmaceutical firms in Enugu State, Nigeria

One-Sample Kolmogorov-Smirnov Test

	Digital supplier integration has significantly reduced operational waste in pharmaceutical firms in Enugu State by enabling seamless communication and accurate demand forecasting.	With digital integration, pharmaceutical firms in Enugu State have minimized inventory spoilage and expiry through real-time tracking of supply deliveries and stock levels.	Improved digital coordination with suppliers has enhanced production planning in Enugu pharmaceutical firms, resulting in a marked decrease in material wastage.	Pharmaceutical companies in Enugu State now experience lower waste generation due to automated order processing systems that eliminate errors associated with manual data handling	By integrating digital supplier platforms, firms in the pharmaceutical sector in Enugu have strengthened resource optimization, leading to a significant reduction in waste and operational inefficiencies.
N	264	264	264	264	264
Uniform Parameters ^{a,b}	Minimum 1 Maximum 5	Minimum 1 Maximum 5	Minimum 1 Maximum 5	Minimum 1 Maximum 5	Minimum 1 Maximum 5
Most Extreme Differences	Absolute .587 Positive .114 Negative -.587	Absolute .576 Positive .095 Negative -.576	Absolute .598 Positive .098 Negative -.598	Absolute .598 Positive .098 Negative -.598	Absolute .595 Positive .106 Negative -.595
Kolmogorov-Smirnov Z	9.540	9.355	9.724	9.724	9.663
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000

a. Test distribution is Uniform.

b. Calculated from data.

Decision Rule

If the calculated Z-value is greater than the critical Z-value (i.e $Z_{cal} > Z_{critical}$), reject the null hypothesis and accept the alternative hypothesis accordingly.

Result

With Kolmogorov-Smirnon Z – value ranges from $9.355 < 9.724$ and on Asymp. Significance of 0.000, the responses from the respondents as display in the table is normally distributed. This affirms the assertion of the most of the respondents that Digital inventory management systems had significant positive relationship with operational cost reduction in pharmaceutical firms in Enugu State, Nigeria.

Decision

Furthermore, comparing the calculated Z- value ranges from $9.355 < 9.724$ against the critical Z- value of .000 (2-tailed test at 95percent level of confidence) the null hypothesis were rejected. Thus the alternative hypothesis was accepted which states that Digital inventory management systems had significant positive relationship with operational cost reduction in pharmaceutical firms in Enugu State, Nigeria.

Discussion of Findings

Digital Supplier Integration and Waste Reduction

From the result of hypothesis one, the calculated Z- value ranges from $9.232 < 10.032$ against the critical Z- value of .000 which implies that Digital supplier integration had significant positive relationship with waste reduction of pharmaceutical firms in Enugu State, Nigeria. In the support of the result in the literature review, Martinez et al. (2020) conducted a study on the digital supplier integration's impact on waste in European pharmaceutical supply chains through case studies of eight pharmaceutical companies in Spain, Germany, and Netherlands. The studies revealed that waste reduction mechanisms included earlier detection of supplier quality issues before materials were incorporated into production, more accurate sharing of demand information that reduced overproduction, better coordination on material shelf lives that reduced expiration waste, and enhanced visibility into supplier inventory positions that enabled more responsive procurement.

Okonkwo and Eze (2022) conducted a study on the digital supplier integration practices and waste reduction among 87 pharmaceutical firms in Lagos State. The finding indicated that better supplier coordination through digital integration enabled more responsive procurement that reduced inventory buffers and associated expiration risks. Wang and Zhang (2022) conducted a study on the effect of supplier relationship quality on the relationship between digital supplier integration and waste reduction in pharmaceutical supply chains. This finding showed that pharmaceutical firms should develop both digital integration capabilities and strong supplier relationships to maximize waste reduction.

Digital Inventory Management Systems and Operational Cost Reduction

From the result of hypothesis one, the calculated Z- value ranges from $9.355 < 9.724$ against the critical Z- value of .000 which implies that Digital inventory management systems had significant positive relationship with operational cost reduction in pharmaceutical firms in Enugu State, Nigeria. In the support of the result in the literature review,

Rodriguez and Patel (2021) conducted a study on the 178 pharmaceutical manufacturers across North America examining the impact of digital inventory management systems on operational costs. The study identified automation of routine tasks, optimization of inventory levels, and reduction of stock-out incidents as key mechanisms through which digital systems reduced costs. Nwankwo et al. (2023) conducted a study on the digital inventory management systems and operational cost reduction specifically in pharmaceutical firms in Nigeria's South-East region. Particularly strong relationships emerged between automated reorder systems and expired product waste reduction, and between real-time inventory visibility and stock-out cost reduction. The study documented that pharmaceutical firms with advanced digital inventory systems achieved 30-50 percent reductions in expired product waste and 25-40 percent reductions in stock-out related costs compared to firms with manual inventory systems. Zhang and Wang (2023) conducted a study on the effect of organizational discipline and process compliance on the relationship between digital inventory management systems and operational cost reduction. This finding has important implications for pharmaceutical firms' implementation approaches. Collectively, empirical research provides strong evidence that digital inventory management systems significantly reduce operational costs in pharmaceutical operations across multiple cost categories including inventory carrying costs, warehousing expenses, labor costs, waste from expired products, and costs from stock outs and expedited shipments.

Summary of Findings, Conclusion and Recommendation

Summary of findings

- i. Digital supplier integration had significant positive relationship with waste reduction of pharmaceutical firms in Enugu State, Nigeria. ($Z = 10.032$, $P = 0.5$) this implies that pharmaceutical firms in Enugu State that digitally integrate their suppliers are able to reduce waste by improving information sharing, coordination, and procurement accuracy, thereby minimizing overstocking, expiration, and material losses.
- ii. Digital inventory management systems had significant positive relationship with operational cost reduction in pharmaceutical firms in Enugu State, Nigeria. ($Z = 9.724$, $P = 0.5$). It implies that pharmaceutical firms in Enugu State that adopt digital inventory management systems are able to reduce operational costs by improving stock control, minimizing holding and storage costs, reducing stockouts and emergency purchases, and enhancing overall efficiency in inventory-related operations.

Conclusion

The study concluded that digital supplier integration and digital inventory management systems had significant positive relationship with waste reduction and cost reduction in pharmaceutical firms in Enugu State, Nigeria. The study demonstrates that digital supply-chain integration is a strategic imperative for pharmaceutical firms seeking to improve cost efficiency in Enugu State, Nigeria. Digital supplier integration and digital inventory management systems serve as key drivers of waste reduction and operational cost savings, respectively. The findings underscore the importance of investing in digital technologies to strengthen supply-chain coordination, enhance operational performance, and maintain competitiveness in an increasingly dynamic and regulated pharmaceutical environment.

Recommendations

Based on the findings of the study, the following recommendations are made:

- i. Pharmaceutical firms in Enugu should invest in and strengthen digital supplier integration systems to enhance real-time information sharing and collaboration with suppliers. This will help firms improve procurement planning, reduce overstocking and product expiration, minimize material waste, and achieve more efficient use of resources.
- ii. Pharmaceutical firms should adopt and fully utilize digital inventory management systems to enable accurate tracking of stock levels and inventory movement. This will support better inventory control, reduce holding and operational costs, prevent stockouts and emergency purchases, and ultimately improve overall cost efficiency and operational performance.

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