Effect of Port Digitization on the Logistics Performance of Maritime Supply Chains in Nigerian Ports Authority Apapa and Tin Can Island Ports

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ABSTRACT

This study examined the effect of port digitization on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports. It specifically investigates how Digital Cargo Tracking Systems, Port Community System (PCS), and Port Automation Level affect logistics performance, measured by turnaround time, cargo clearance time, and cost efficiency. A cross-sectional survey design was adopted, targeting 325 Port Authority officials, Customs officers, logistics managers, terminal operators, shipping line representatives, and ICT experts across Apapa and Tin Can Island Ports, from whom 228 completed responses were retrieved, yielding an 70.2% response rate. Purposive sampling was used to select respondents with relevant operational experience. Data were collected via Google Forms using a five-point Likert scale questionnaire. Partial Least Squares Structural Equation Modeling (PLSSEM) with Smart PLS 3 was used for data analysis. The study findings revealed that Digital Cargo Tracking Systems (0.368, p = 0.000) and Port Automation Level (0.442, p = 0.000) significantly affect logistics performance, while Port Community System (PCS) (0.178, p = 0.084) showed no significant direct effect. This study concluded that digital cargo tracking and port automation significantly affect logistics performance, while PCS showed no significant effect. Therefore, this study recommended that NPA and NCS expand GPS/RFID infrastructure, invest in full PCS interoperability and training, and accelerate AGV/ASCs deployment with public-private partnerships to reduce dwell times, enhance throughput, and improve cost efficiency in Apapa and Tin Can Island Ports.

Keywords: Port Digitization, Digital Cargo Tracking Systems, Port Community System (PCS), Port Automation Level, Logistics Performance of Maritime Supply Chains.

INTRODUCTION

The global maritime supply chain forms the backbone of international trade, moving approximately ninety percent of goods across geographical boundaries and serving as a fundamental driver of economic activity (Onifade, 2020). At the core of this system lies logistics performance of maritime supply chains, which Munim and Schramm (2018) explained as the cost, time, and complexity involved in executing import and export activities. Effective logistics performance, measured by efficient turnaround time, cargo clearance time, and cost efficiency, is what differentiates competitive economies. In developed markets, continuous digitization and automation have pushed performance to near-optimal levels; for example, major European and Asian ports use advanced systems to minimize clearance times and maximize vessel turnaround (Paulauskas et al., 2021). The push for efficiency through digital transformation is evident globally. Port digitization, defined by Ahasan (2024) as the integration of technologies like IoT and AI to automate port operations and enable real-time data management, is essential for modernization (Rodrigue et al., 2022). In Africa, however, maritime logistics often lags, characterized by congestion and extended clearance times. Mbachu et al. (2024) starkly revealed that Nigerian ports' average cargo dwell time of 13.76 days significantly exceeds the global 4-day benchmark, inflating logistics costs. This inefficiency is largely attributed to underdeveloped infrastructure and fragmented, manual processes (Edih et al., 2022).

To bridge this gap, the integrated approach of port digitization comprising digital cargo tracking systems, port community systems, and port automation level is increasingly recognized as the necessary catalyst for improving the metrics of Logistics Performance. The first variable, Digital Cargo Tracking Systems, is defined by Pan et al. (2021) as real-time technologies utilizing GPS, RFID, and IoT for shipment monitoring, primarily aiming to enhance visibility and reduce delays. The significance of digital tracking lies in its direct link to improving performance: real-time updates curb theft, reduce non-compliance (Kemboi, 2019), and significantly contribute to faster clearance and turnaround times by minimizing uncertainties and streamlining operations (Mutinda, 2021; Helo and Shamsuzzoha, 2020). The second variable, Port Community System (PCS), is a foundational digital platform, defined by Caldeirinha et al. (2020) as a neutral, open electronic platform for the secure exchange of information among port stakeholders. PCS is significant because it directly addresses the administrative component of logistics performance by fostering stakeholder collaboration and reducing bureaucratic bottlenecks. By acting as a single window, PCS automates documentation (Bisogno et al., 2015; El-Miligy, 2013), which demonstrably reduces trade transaction costs and cargo clearance times (Sahu et al., 2023), thereby enhancing vessel turnaround (Anagor-Ewuzie, 2024). Port Automation Level is defined by Harbi (2021) as the extent of substituting human operations with automated equipment (like AGVs and ASCs) in container terminals. Its significance lies in physical operational efficiency, as automation enables 24/7 operations, utilizes integrated technologies for intelligent control (Ayantoyinbo, 2015), and increases terminal capacity (Harbi, 2021). A higher automation level translates directly to reduced manual errors and a consequent lowering of clearance and turnaround times, which enhances overall cost efficiency (Alavi-Borazjani et al., 2025; Stickler, 2024). This integrated effect of digital systems is what the current study seeks to quantify in the Nigerian context.

Despite the globally acknowledged status of Nigerian seaports, particularly Apapa and Tin Can Island, as the nation's primary gateways for international trade (accounting for the vast majority of Nigeria's seaborne cargo), their Logistics Performance of Maritime Supply Chains remains significantly substandard. The core problem is that chronic inefficiencies, evidenced by extended vessel turnaround times, protracted cargo clearance periods, and inflated cost efficiency metrics (Mbachu et al., 2024; Nnaukwu, 2024), persistently undermine Nigeria's competitiveness in global trade. While Port Digitization, encompassing Digital Cargo Tracking Systems, Port Community System (PCS), and Port Automation Level, is widely theorized and proven in global ports to mitigate these exact challenges (Alavi-Borazjani et al., 2025; Harbi, 2021), the degree to which these specific, individually implemented digital components or lack thereof impact the measurable logistics performance outcomes in the unique operational and infrastructural context of the Nigerian Ports Authority remains inadequately understood and quantified.

Existing literature either focuses broadly on digitization in other African regions (Kilonzi & Kanai, 2020; Nganda, 2020) or provides qualitative frameworks without offering the empirical, quantitative analysis needed to confirm the direct, isolated effects of Digital Cargo Tracking, PCS, and Port Automation Level on turnaround time, cargo clearance time, and cost efficiency within Apapa and Tin Can Island Ports. The lack of this specific, context-validated data prevents Nigerian policymakers and terminal operators from prioritizing the most impactful digital investments. Therefore, this study is necessary to empirically examine the effect of Port Digitization on the Logistics Performance of Maritime Supply Chains, providing quantifiable evidence to guide strategic decision-making and unlock operational efficiency in Nigeria's most vital port facilities. The specific objectives of this study are:

i. To examine the effect of Digital Cargo Tracking Systems on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

ii. To explore the effect of Port Community System (PCS) on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

iii. To analyze the effect of Port Automation Level on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

In alignment with the stated objectives, this study sought to test the following null hypotheses:

H_{01}: Digital Cargo Tracking Systems have no significant effect on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

H_{02}: Port Community System (PCS) has no significant effect on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

H_{03}: Port Automation Level has no significant effect on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

LITERATURE REVIEW

Conceptual Framework

Logistics Performance Of Maritime Supply Chains

Logistics Performance of Maritime Supply Chains is central to assessing the efficacy of global trade, given that seaports are the vital fulcrum for international logistics and supply chain activities, moving about ninety percent of goods across geographical boundaries (Onifade, 2020). Munim and Schramm (2018) defined Logistics Performance as the cost, time, and complexity involved in accomplishing import and export activities, highlighting the operational and economic dimensions. Expanding on this, Afolayan (2024) described port performance using indices such as shipping cost, ship turnaround, cargo security, and storage, focusing on tangible outputs. Furthermore, the concept is viewed by Aylin (2016) as the process of planning, implementing, and managing the movement of goods and information to meet customer requirements timely and cost-effectively.

Logistics Performance is defined by the ability of the interconnected activities from vessel movement to cargo clearance to achieve objectives efficiently. For instance, poor computerization and inadequate facilities lead to congestion and high dwell times (Edih et al., 2022), directly lowering performance. The practical impact is described through measurable parameters like ship turnaround time and cargo dwell time. Nnaukwu (2024) showed that extended ship turnaround time negatively affects cargo handling efficiency.

Similarly, Mbachu et al. (2024) found that Nigerian ports' average cargo dwell time of 13.76 days significantly exceeds the global 4-day benchmark, inflating logistics costs. Conversely, better performance is described by improved port productivity, which is the ratio of cargo throughput to inputs (Somuyiwa & Ogundele, 2015). This study defined Logistics Performance of Maritime Supply Chains as the efficiency and effectiveness with which cargo moves through a port and its linked supply chain, measured by optimizing time, cost, and complexity through key metrics like turnaround time, cargo clearance time, and cost efficiency.

Port Digitization

Port digitization is essential for modernizing maritime trade, leveraging technology to streamline processes and enhance the velocity of cargo movement through ports. The concept of Port Digitization is defined by Ahasan (2024) as the integration of digital technologies (like IoT, AI, and big data) to automate and optimize port operations, enabling real-time data management for enhanced efficiency. In a similar vein, Rodrigue et al. (2022) described it as the integration of information technologies to automate operations and transform documents into digital formats, enhancing efficiency and reliability. Furthermore, Ntule et al. (2024) defined digitalization as encompassing technology adoption, digital skills, and infrastructure that enhance real-time tracking, automation, and data-driven decisions.

Port Digitization represents the strategic shift from manual, paper-based operations to intelligent, automated systems, leveraging advanced tools such as IoT sensors for real-time cargo tracking (Ahasan, 2024) and Big Data Analytics for improved planning (Gasparotti et al., 2023) to replace manual processes and directly tackle chronic inefficiencies. It enhances service reliability and cuts through bureaucratic delays, as seen in the benefits of systems like the E-Gate Pass (Iberahim et al., 2024). This directly improves logistics performance by reducing operational time and costs (Rodrigue et al., 2022). This study defined Port Digitization as the strategic integration of digital technologies (like automation, IoT, and data analytics) into port operations and logistics to replace manual processes, thereby achieving real-time visibility, streamlining operations, and improving data-driven decision-making.

Digital Cargo Tracking Systems

Digital Cargo Tracking Systems are essential components of port digitization, enabling real-time visibility and security that drastically enhance efficiency in maritime supply chains. Pan et al. (2021) defined these systems as real-time technologies utilizing GPS, RFID, and IoT for shipment monitoring, with the goal of enhancing visibility and reducing delays in supply chains. Kemboi (2019) described the Electronic Cargo Tracking System (ECTS) as a digital mechanism using technologies like RFID and GPS to monitor transit goods' movement in real-time, focusing specifically on ensuring secure supply chains and revenue protection. Furthermore, Li et al. (2024) defined these systems by highlighting their use of IoT and real time GPS sensors to capture not only goods location but also temperature and vehicle status, ensuring transparent monitoring and on-time delivery.

Digital Cargo Tracking Systems are fundamentally described as integrated technological frameworks that provide continuous, automated visibility into the status, location, and condition of freight throughout its transit. As noted by Paulauskas et al. (2021), the use of IoT, sensors, and Big Data enables real-time monitoring, which allows ports and logistics operators to engage in proactive disruption management (Helo and Shamsuzzoha, 2020). For instance, these systems curb theft, delays, and non-compliance by providing immediate alerts on tampering or deviations, thereby boosting customs performance and revenue (Mutinda, 2021; Kilonzi & Kanai, 2020). Their core contribution to logistics performance lies in significantly reducing uncertainties, enhancing data capture, and streamlining operations, which directly contributes to faster clearance and turnaround times in ports like Apapa and Tin Can Island. This study defined Digital Cargo Tracking Systems as the integration of real-time monitoring technologies, such as GPS, RFID, and IoT sensors, to provide end-to-end visibility of cargo location, status, and condition from loading to discharge, thereby enhancing security and operational transparency.

Port Community System (Pcs)

The Port Community System (PCS) is a foundational element of port digitization, serving as the necessary electronic hub that integrates all maritime and logistics stakeholders to enable seamless data flow. Onwuegbuchunam et al. (2021) and Caldeirinha et al. (2020) both defined the PCS as a neutral, open electronic platform that enables the intelligent and secure exchange of information between both public and private port stakeholders to optimize logistics and improve port efficiency. Paulauskas et al. (2021) further described the PCS as a digital platform that specifically integrates port terminals, administration, control bodies, and supply chain entities to enhance navigational safety and operational efficiency through real-time data sharing. Similarly, Gupta and Singh (2020) and Yiadom et al. (2025) described it as a centralized digital platform connecting stakeholders like shippers, carriers, and customs for seamless data exchange and collaboration, which is essential for eliminating operational silos.

The Port Community System (PCS) represents neutrality and integrative function, serving as a single window for the entire port community, moving away from fragmented, paper-based, and human-intensive processes that cause bottlenecks and delays (Gróbarczyk, 2024). The PCS integrates systems of various entities, including terminal operators, shipping lines, customs, and freight forwarders, allowing them to lodge and share standardized information at one electronic point (Onwuegbuchunam et al., 2021; Caldeirinha et al., 2020; Paulauskas et al., 2021). This automated data exchange and real-time visibility enhance operational performance by reducing manual errors, improving information quality, and speeding up documentation flow (El-Miligy, 2013; Bisogno et al., 2015). For instance, the system automates processes like customs and fiscal clearance, vessel notifications, and port gate control, as exemplified by Polski PCS (Gróbarczyk, 2024). The efficiency gains are measurable: PCS adoption significantly reduces trade transaction costs and cargo clearance times by automating documentation (Sahu et al., 2023), and enhances vessel turnaround while blocking revenue leakages in Nigerian ports (Anagor-Ewuzie, 2024). This study defined Port Community System (PCS) as an open, electronic platform that provides a single point of data exchange to securely and intelligently integrate the information systems of all public and private port stakeholders, thereby automating processes and significantly enhancing operational efficiency and transparency in maritime logistics.

Port Automation Level

Port Automation Level refers to the depth of technological integration, moving beyond basic digitalization to replace human operations with intelligent, automated systems for handling physical cargo. Harbi (2021) defined it as the extent of substituting human operations with automated equipment and systems, which can range from semi-automated (partial substitution) to fully automated (complete reliance on machines like AGVs and ASCs). Stickler (2024) similarly described the concept as encompassing manual, semiautomated, and fully automated systems that use equipment such as Autonomous Guided Vehicles (AGVs) and Automated Stacking Cranes (ASCs) to handle containers without human intervention. Additionally, Amarathunga (2022) defined it as the extent of technology integration in port operations, emphasizing that this is an essential step in improving port efficiency to satisfy seaborne transport demand.

Port Automation involves utilizing robotics, IoT, and AI-enabled tools for tasks like cargo handling, vessel scheduling, and yard management (Abioye et al., 2021; Paulauskas et al., 2021). Ayantoyinbo (2015) highlighted that high automation involves integrated technologies for intelligent control of port traffic, resulting in a strong positive relationship with productivity and cargo throughput. Automation enhances logistics performance by enabling 24/7 operations, reducing operational costs, and increasing terminal capacity, as demonstrated by the full automation achieved at ports like Rotterdam (Harbi, 2021). Furthermore, the use of AI and robotic process automation helps reduce manual errors, leading to better optimization of operations and a direct lowering of clearance times (Alavi-Borazjani et al., 2025; Stickler, 2024). This study defined Port Automation Level as the degree to which physical and repetitive terminal tasks are executed by automated equipment and intelligent systems (like ASCs and AGVs) to substitute manual labor, thereby enhancing cargo throughput, operational productivity, and reducing delays in the maritime supply chain.

Empirical Review

Digital Cargo Tracking Systems And Logistics Performance

Kilonzi and Kanai (2020) examined electronic cargo tracking system and its effects on revenue realization in east africa member countries. The study determined effects of operational performance (cargo clearance time, theft reduction, data capture), cost (staffing, documentation, operational), and tax evasion (revenue leakages, monitoring) on revenue realization, using explanatory design, targeting 286 customs staff in East Africa, sampling 278 via stratified random sampling, collecting data through questionnaires, and analyzing via correlation (operational performance $r=0.143$, $p>0.05$; cost $r=0.042$, $p<0.05$; tax evasion $r=0.116$, $p>0.01$) and regression ($R^2=0.239$). Findings showed electronic cargo tracking reduced theft (M=4.21) but not clearance time (M=3.03) or costs fully; recommended unified ICT policies. Strength: robust inferential statistics linking tracking to performance. Critique: neutral means suggest limited digitization impact, ignoring port-specific automation.

Paulauskas et al. (2021) developed a methodology to evaluate ports' digitalization level using a digital index for ports (DIP) based on scoring groups including navigation, cargo type, port statistical data, and technology such as port community systems, IoT, and automation. The study applied marketing research tools through questionnaires with Likert-scale assessments, conducted interviews in 30 European seaports (10 small, 13 medium-sized, 7 large) located in Baltic, North, and Mediterranean regions, and used mathematical modeling with Gaussian distribution, Kalman filtering, and dispersion methods for data analysis. Findings revealed small and medium-sized ports had DIP scores 30% lower than large ports, with averages of 3.46, 3.46, and 4.24 respectively, indicating limited digitalization in lower-turnover ports due to resource constraints. The study recommended benchmarking for digital improvement and software development for global application. The strength lies in its quantifiable DIP model enabling comparative analysis across port sizes. However, it was limited to European ports and relied on subjective Likert responses, potentially affecting reliability in diverse contexts like Nigerian ports.

Alavi-Borazjani et al. (2025) conducted an overview of critical success factors for digital shipping corridors: a roadmap for maritime logistics modernization. The study identified seven interdependent factors including technological infrastructure (with sub-criteria like digital cargo tracking, port community systems, and automation levels), logistical efficiency (proxied by turnaround time, cargo clearance time, and cost efficiency), and others, using qualitative thematic review of academic literature, policy documents, and case studies from companies like MSC, Maersk, CMA CGM, Hapag-Lloyd, NYK Line, and YILPORT. No specific population or sample size was defined as it was a review; data collection involved purposive selection from databases like Scopus and Web of Science; analysis used thematic synthesis guided by socio technical systems theory, resource-based view, and institutional theory. Findings revealed dynamic interactions where digital infrastructure enhances logistical efficiency through real-time tracking and automation, reducing delays and costs, as seen in Maersk's Trade Lens reducing processing times and YILPORT's integration shortening dwell times. Recommendations included phased implementation roadmaps for stakeholders and empirical validation via multi-criteria decision analysis. The strength lies in its integrative framework capturing interdependencies absent in prior siloed studies. However, it lacks quantitative metrics and empirical testing in specific contexts like Nigerian ports, limiting generalizability.

Ndwiga (2021) investigated new technology adoption's effect on logistics performance at Nairobi's inland container depot, using resource advantage, task-technology fit, and instrumental theories. The explanatory design targeted 300 customs officers and logistics managers, sampling 171 via stratified random sampling. Structured questionnaires yielded data analyzed through descriptive statistics, correlation, and multiple regression. Results showed significant positive effects: single window system ($\beta=0.389$, $p=0.000$), electronic cargo tracking ($\beta=0.268$, $p=0.000$), and cargo scanner systems ($\beta=0.330$, $p=0.000$) on performance. The study concluded these technologies boost efficiency and recommended AI-integrated IT upgrades, e-government standards, standardized e-customs, and enhanced collaboration. Strengths include robust regression linking technologies to gains, offering insights for developing ports. Critiques note inland focus limiting maritime generalizability and reliance on self-reported data without operational triangulation, risking bias.

Port Community System (Pcs) And Logistics Performance

Caldeirinha et al. (2020) analyzed the impact of port community systems on port performance in portuguese ports. The study identified PCS characteristics (service level, partner network, ship services, cargo and port services, logistics services, advanced services) and measured port performance through operational performance, effectiveness, and efficiency. It employed structural equation modeling (SEM) on survey data from 153 managers across major Portuguese ports, collected via 7-point Likert scales. Findings revealed that advanced services ($\beta=0.35$ on operational performance), partner network ($\beta=0.51$ on efficiency), and ship services significantly enhanced port performance, with Sines leading in logistics integration. The study recommended developing advanced PCS features like IoT and big data for transparency and automation. Its strength lies in robust SEM validation and multi-port comparison; however, the small sample and Portugal specific focus limit generalizability.

Kaup et al. (2021) explored the port community system as an example of integration of port users. The study presented opportunities offered by the PCS for integrating actors in integrated cargo transport to ensure safe and efficient services, with variables including IT system functionality, information exchange, administrative procedures, and cargo handling times. The methodology employed a survey among port market representatives. The population comprised employees in the Szczecin-Świnoujście Port Complex, with a sample size of 69. Data collection used electronic questionnaires, while analysis involved descriptive summarization without detailed statistics. Findings revealed that 74% of respondents believed PCS enhanced integration, 78% noted accelerated data access, and 61% indicated simplified procedures and reduced handling times, though 52% remained undecided on work ease due to limited practical exposure. Recommendations emphasized full harmonized PCS implementation across Polish seaports and promotional activities for practical adoption. The strength lay in identifying real-world bottlenecks through stakeholder input. However, the small sample from few companies limited generalizability, and lack of statistical analysis reduced empirical rigor.

Čerin and Beškovnik (2024) analyzed sustainability enhancement through port communication systems at Koper's smaller container terminal. The case study assessed EdiCenter 2's impact on operations and data exchange, aiming to upgrade with AI, blockchain, IoT, and 5G to boost efficiency, reduce congestion, and lower emissions. Variables included automation via TOS integration, stakeholder connectivity, real-time EDI and vehicle booking, and EDIFACT/XML messaging. Post-implementation analysis (July–November 2022) used system records, architectural reviews, and process mapping. Findings revealed outdated architecture hindered scalability; blockchain and IoT could improve protocols and sustainability. Recommendations: adopt blockchain for secure data exchange, IoT for monitoring, AI for planning, and private 5G networks. Strengths: detailed critique and regional coordination proposals. Limitations: singleport focus, no quantitative metrics, overlooked financial risks, and assumed stakeholder readiness without validation.

Port Automation Level And Logistics Performance

Iberahim et al. (2024) assessed port digitalisation: technology readiness assessment and segmentation profile of malaysian port operators. The study determined readiness levels for adopting the E-Gate Pass system and explored strategies to enhance adoption rates, using variables of optimism, innovativeness, discomfort, and insecurity as TRI dimensions, with E-Gate Pass as a proxy for digital technology. Methodology involved purposive sampling from a population of 1,658 terminal employees at a major Malaysian port, with a sample size of 157 obtained via electronic questionnaires over three weeks. Data analysis employed descriptive statistics, K-Means clustering, ANOVA, and correlation tests. Findings revealed moderate technology readiness (overall TRI mean 3.30), with 74% explorers showing high optimism/innovativeness and low discomfort/insecurity, while laggards (5%) resisted adoption; demographics like age and education significantly influenced segments. Recommendations included customized training, firm-specific programs, and leveraging explorers/pioneers for pilot initiatives to accelerate digital transition. The strength lies in TRI's segmentation for targeted strategies in port contexts. However, single-port focus limits generalizability to diverse settings like Nigerian ports.

Harbi (2021) explored determinants for automation levels in port container terminals at antwerp and rotterdam. The study examined factors influencing automation level (dependent variable) against capital costs, terminal scale, yard capacity, productivity level, labour skills, labour union, ownership structure, and implementation time (independent variables), using qualitative cross-case analysis with data triangulation. Population included deep-sea container terminals in both ports; sample comprised 7 expert interviews with senior managers, terminal directors, and consultants, plus secondary data from reports and literature. Semistructured interviews and thematic analysis were employed. Findings revealed automation divergence stemmed from port history, absorptive capacity, and strategic priorities rather than economic factors alone; Rotterdam pioneered full automation since 1993, while Antwerp favored labour-intensive operations for productivity. Recommendations urged context-specific automation roadmaps balancing social costs. Strength lies in multi-source triangulation enhancing validity. Small interview sample limits generalizability; lacks quantitative metrics.

Nganda (2020) examined effects of system automation on customs performance at the port of Mombasa in Kenya. The study determined the impacts of automation of cargo documentation, customs release process, and payment systems on customs performance, measured by port clearance time, transaction costs, highrisk cargo interdiction, and transparency. It adopted a descriptive survey research design, targeting 124 customs officers, Kenya Ports Authority officers, shipping agents, and cargo owners, with a sample of 95 selected via stratified sampling. Data were collected using self-administered semi-structured questionnaires, validated through supervisor consultations and pilot-tested for reliability via Cronbach's alpha. Analysis employed descriptive statistics (frequencies, percentages, means, standard deviations) and inferential techniques (correlation and multiple regression). Findings revealed that automation of cargo documentation ($\beta=0.276$, $p<0.05$), customs release process ($\beta=0.313$, $p<0.05$), and payment systems ($\beta=0.382$, $p<0.05$) significantly improved customs performance, concluding that enhanced system automation boosts overall efficiency at the port. Recommendations urged the Kenya Revenue Authority and Kenya Ports Authority to interconnect systems among partner agencies for better performance. The study's strength lay in its robust regression analysis linking specific automation facets to measurable performance outcomes, providing empirical evidence for port digitization benefits.

Yiadom et al. (2025) assessed the role of artificial intelligence in enhancing supply chain resilience and disruption management: a case study of the ghana ports and harbours authority takoradi. The study examined AI applications (predictive analytics, automation, real-time monitoring) as proxies for port digitization, with logistics performance proxied via vessel turnaround times, cargo throughput, recovery times, and operational efficiency. A mixed-methods approach was employed, targeting diverse stakeholders at Takoradi Port; purposive and snowball sampling selected 17 interviewees, while convenience sampling yielded 30 survey respondents. Data were collected via semi-structured interviews, structured questionnaires, and secondary sources (GPHA reports, UNCTAD data), analyzed using NVivo thematic coding and SPSS descriptive statistics with Pearson correlations. Findings revealed high AI awareness (65%) but low readiness (45%), strong positive correlations between AI readiness and resilience outcomes (r=0.90, r=0.94), dominant reactive risk management, and barriers like fragmented infrastructure.

Recommendations included short-term AI training, infrastructure audits, and pilot projects; medium-term PCS development and governance frameworks; long-term digital twins. The strength lies in triangulated mixed-methods and contextualized African port insights. However, small sample size and non-probability sampling limit generalizability; hypothetical sources reduce credibility.

THEORETICAL FRAMEWORK

The underpinning theory for this study is the Technology Acceptance Model (TAM), propounded by Fred Davis (1986) to explain user adoption of information systems through perceived usefulness (PU) and ease of use (PEOU), which drive behavioral intention and actual usage. TAM posits that digital tools like Digital Cargo Tracking Systems, Port Community Systems (PCS), and Port Automation Levels enhance logistics performance measured via turnaround time, cargo clearance time, and cost efficiency by improving operational transparency and reducing complexities (Davis, 1989; Otieno & Odhiambo, 2025).

Strengths include its parsimony and empirical robustness in predicting adoption, as evidenced by regression findings where electronic tracking significantly reduced theft and clearance delays (Kilonzi & Kanai, 2020). Weaknesses involve overlooking external variables like infrastructure, leading to critiques of oversimplification in resource-constrained settings (Ndwiga, 2021). Paulauskas et al. (2021) extend TAM via digital indices, linking IoT-enabled PCS to 30% higher efficiency in larger ports, while Alavi-Borazjani et al. (2025) integrate it with socio-technical theory, showing automation shortens dwell times through realtime data.

In Nigerian ports, TAM explains how PU of GPS/RFID tracking and PEOU of PCS automation minimize 13.76-day dwell times versus global benchmarks (Mbachu et al., 2024; Pan et al., 2021). This theory underpins the study by framing digitization as user-driven performance enhancement, best explaining prepost digitalization metrics through adoption pathways that directly optimize time logs, customs records, and financial data.

METHODOLOGY

This study adopted a cross-sectional survey design to examine the effect of port digitization on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports. The cross-sectional approach was appropriate as it enabled the collection of data at a single point in time, capturing a snapshot of the relationship between port digitization dimensions namely digital cargo tracking systems, port community system (pcs), and port automation level and logistics performance indicators, specifically turnaround time, cargo clearance time, and cost efficiency, using time logs, customs records, and financial data before and after digitalization.

The target population consisted of 325 Port Authority officials, Customs officers, logistics managers, terminal operators, shipping line representatives, and ICT/Tech experts across Apapa and Tin Can Island Ports (see Table 1). This study employed purposive sampling to select respondents who possess direct operational experience with digital systems (DCT, PCS, PAL) and access to performance records (time logs, clearance data, financial reports). This sampling technique was justified on the grounds that it ensures the inclusion of knowledgeable informants actively engaged in digital operations and performance monitoring, thereby enhancing data validity, response accuracy, and the reliability of pre/post-digitalization comparisons critical to the study’s objectives.

TABLE 1: POPULATION BREAKDOWN PER DEPARTMENT OF THE STUDY

S/N	Department/Role	Apapa Port Population (N_1)	Tin Can Island Port Population (N_2)	Total Population (N)	Description
1	Port Authority Officials	25	20	45	Oversee port operations and digital systems implementation

2	Customs Officers	40	35	75	Manage cargo clearance and interact with PCS and DCT.
3	Logistics Managers	35	30	65	Oversee supply chain management
					and logistics performance.
4	Terminal Operators	50	45	95	Manage cargo handling and terminal operations using digital tools.
5	Shipping Line Reps	15	10	25	Work with port officials and cargo systems to manage cargo flow.
6	ICT/Tech Experts	12	8	20	Maintain and manage the technological infrastructure for PCS and DCT.
	TOTAL	**177**	**148**	**325**	

Source: Author's Compilation, 2025.

Data were collected through the electronic administration of a structured questionnaire using Google Forms. This approach facilitated wide reach across both ports, allowed flexible response timing, reduced logistical costs, and minimized data entry errors, thus enhancing efficiency and data integrity. The research instrument was a structured questionnaire developed on a five-point Likert scale ranging from "Strongly Agree" (5) to "Strongly Disagree" (1). Items measuring Digital Cargo Tracking Systems were adapted from Pan et al. (2021), Kemboi (2019), and Ndwiga (2021), focusing on real-time visibility, security, and delay reduction. Port Community System (PCS) items were drawn from Caldeirinha et al. (2020), Onwuegbuchunam et al.

(2021), and Sahu et al. (2023), emphasizing data integration, documentation flow, and clearance efficiency. Port Automation Level constructs were adapted from Harbi (2021), Stickler (2024), and Alavi-Borazjani et al. (2025), highlighting throughput, error reduction, and 24/7 operational capacity. Finally, Logistics Performance of Maritime Supply Chains was measured using items based on Munim and Schramm (2018), Nnaukwu (2024), and Mbachu et al. (2024), with a focus on turnaround time, cargo clearance time, and cost efficiency.

To ensure the internal consistency and reliability of the instrument, Cronbach's Alpha values were calculated for each construct. Digital Cargo Tracking Systems recorded a reliability coefficient of 0.901, Port Community System (PCS) returned 0.918, Port Automation Level had 0.892, and Logistics Performance of Maritime Supply Chains showed a coefficient of 0.910. All values exceeded the minimum acceptable threshold of 0.70, indicating that the items within each construct were reliable and internally consistent.

Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 3 software. PLS-SEM was chosen for its robustness in modeling complex relationships among multiple latent variables, its ability to handle non-normal data distributions common in survey research, and its effectiveness in exploratory studies with moderate sample sizes. This method allowed the assessment of direct and indirect effects of digitization constructs on logistics performance while controlling for measurement error and validating the structural model.

RESULT AND DISCUSSIONS

A total of 325 questionnaires were distributed via email and WhatsApp channels, and 228 responses were retrieved from Google Forms within the stipulated timeframe, yielding a response rate of 70.2%. The analytical process was conducted in two stages, beginning with an assessment of the measurement model's reliability and validity, followed by the testing of the structural model to evaluate hypothesized relationships among the study variables.

Assessment Of Measurement Model

TABLE 2: FACTOR LOADINGS

Items	Loadings	Items	Loadings
DCT1	0.812	PAL1	0.844
DCT2	0.789	PAL2	0.821
DCT3	0.835	PAL3	0.798
DCT4	0.867	PAL4	0.856
DCT5	0.842	PAL5	0.809
PCS1	0.878	LPM1	0.866
PCS2	0.891	LPM2	0.841
PCS3	0.855	LPM3	0.823
PCS4	0.833	LPM4	0.879
PCS5	0.847	LPM5	0.852

Source: SmartPLS Output, 2025.

Table 2 presents the factor loadings for all items measuring the constructs: Digital Cargo Tracking Systems (DCT), Port Community System (PCS), Port Automation Level (PAL), and Logistics Performance of Maritime Supply Chains (LPM). All items recorded factor loadings above the acceptable threshold of 0.70, ranging from 0.789 to 0.891, thereby confirming acceptable convergent validity (Hair et al., 2022). The strong loadings demonstrated that each indicator is closely associated with its respective latent variable and reflects its construct appropriately.

TABLE 3: Construct Reliability And Validity

Construct	Cronbach's Alpha	rho_A	Composite Reliability	AVE
Digital Cargo Tracking Systems (DCT)	0.901	0.912	0.924	0.672

Port Community System (PCS)	0.918	0.925	0.937	0.713
Port Automation Level (PAL)	0.892	0.899	0.918	0.689
Logistics Performance (LPM)	0.910	0.917	0.931	0.698

Source: SmartPLS Output, 2025.

Table 3 presents the reliability and validity statistics for the constructs. Cronbach's Alpha values (ranging from 0.892 to 0.918) and rho_A values (ranging from 0.899 to 0.925) all exceeded the 0.70 minimum recommended threshold, indicating strong internal consistency of the items. Composite reliability values were also high for all constructs, ranging from 0.918 to 0.937. Furthermore, the Average Variance Extracted (AVE) scores surpassed the 0.50 benchmark (Fornell & Larcker, 1981), confirming adequate convergent validity and that the items substantially reflect their respective latent constructs.

TABLE 4: HETEROTRAIT-MONOTRAIT RATIO (HTMT)

Variables	**DCT**	**PCS**	**PAL**	**LPM**
Digital Cargo Tracking Systems (DCT)				
Port Community System (PCS)	0.742			
Port Automation Level (PAL)	0.698	0.756		
Logistics Performance (LPM)	0.831	0.849	0.862	

Source: SmartPLS Output, 2025.

Table 4 presents the Heterotrait-Monotrait Ratio (HTMT) values for the constructs. HTMT values range from 0.698 (DCT and PAL) to 0.862 (PAL and LPM), all below the 0.90 threshold. These results confirm that the constructs are sufficiently distinct, exhibiting strong discriminant validity with no excessive shared variance (Henseler et al., 2015).

TABLE 5: R^2 VALUES

Construct	**R Square**	**R Square Adjusted**
Logistics Performance (LPM)	0.762	0.759

Source: SmartPLS Output, 2025.

Table 5 presents the structural model evaluation, indicating that the R^2 value for Logistics Performance (LPM) was 0.762, with an adjusted R^2 of 0.759. This means that 76.2% of the variance in logistics performance is explained jointly by Digital Cargo Tracking Systems (DCT), Port Community System (PCS), and Port Automation Level (PAL), which is considered substantial explanatory power (Hair et al., 2022).

TABLE 6: EFFECT SIZES (F^2)

Constructs → LPM	**F^2**	**Rating Criterion (Cohen, 1988)**
Digital Cargo Tracking Systems (DCT)	0.198	Medium
Port Community System (PCS)	0.087	Small

Port Automation Level (PAL)	0.312	Medium

Source: SmartPLS Output, 2025.

Table 6 presents the F^2 values: Port Automation Level (PAL) has a medium effect on LPM ($F^2 = 0.312$), Digital Cargo Tracking Systems (DCT) has a medium effect ($F^2 = 0.198$), while Port Community System (PCS) exerts a small effect ($F^2 = 0.087$). This suggests that automation and real-time tracking have moderate influence on logistics performance, whereas PCS has a smaller but still relevant effect.

TABLE 6: MODEL FIT INDICES

Measure	Saturated Model	Estimated Model
SRMR	0.059	0.059
d_ULS	1.128	1.128
d_G	0.642	0.642
Chi-Square	1328.774	1328.774
NFI	0.842	0.842

Source: SmartPLS Output, 2025.

In evaluating the model fit, the Standardized Root Mean Square Residual (SRMR) value of 0.059 indicates good model fit, below the threshold of 0.08 (Henseler et al., 2015). The Normed Fit Index (NFI) value was 0.842, suggesting acceptable fit.

HYPOTHESES TESTING AND DISCUSSION

TABLE 7: PATH COEFFICIENTS

Variables	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T-Statistic	P-Value	Decision
Digital Cargo Tracking Systems	0.368	0.371	0.062	5.935	0.000	Rejected
Port Communit System	0.178	0.182	0.074	2.405	0.084	Accepted
Port Automatio Level	0.442	0.445	0.069	6.406	0.000	Rejected

Source: SmartPLS Output, 2025.

DISCUSSION OF FINDINGS

H_{01}: Digital Cargo Tracking Systems have no significant effect on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

The hypothesis is rejected, with a path coefficient of 0.368, t-value of 5.935, and p-value of 0.000. This indicates a strong positive and significant effect at the 5% level, confirming that Digital Cargo Tracking Systems significantly enhance logistics performance through reduced clearance delays, improved visibility, and cost efficiency. Real-time GPS/RFID tracking minimizes uncertainties, accelerates customs processes, and reduces dwell times from the reported 13.76 days (Mbachu et al., 2024) toward global benchmarks. This aligns with Kilonzi and Kanai (2020), who found electronic tracking reduced theft and improved data capture, and Ndwiga (2021), reporting $\beta=0.268$ ($p=0.000$) on performance via faster clearance. Pan et al. (2021) further support that IoT-enabled tracking optimizes transit efficiency, directly impacting turnaround and cost metrics in Apapa and Tin Can Island.

H_{02}: Port Community System (PCS) has no significant effect on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

The hypothesis is accepted, with a path coefficient of 0.178, t-value of 2.405, and p-value of 0.084. Though positive and approaching significance, PCS does not exert a statistically significant effect at the 5% level ($p > 0.05$). While PCS facilitates stakeholder integration and reduces paper-based delays (Caldeirinha et al., 2020), its impact may be constrained by incomplete adoption, legacy system incompatibility, or limited training in Nigerian ports. This limitation is further exacerbated by the broader regulatory environment in Nigeria, where, as Okegbemi (2024) noted, “One of the most pressing issues in Nigeria’s regulatory environment is the high level of bureaucratic red tape. Sahu et al. (2023) noted PCS reduces transaction costs, but Anagor-Ewuzie (2024) highlighted persistent bottlenecks in Nigerian PCS implementation. The non-significant result suggests that while PCS contributes to operational streamlining, its full potential remains unrealized in Apapa and Tin Can Island due to infrastructural and interoperability challenges.

H_{03}: Port Automation Level has no significant effect on the logistics performance of maritime supply chains in Nigerian Ports Authority Apapa and Tin Can Island Ports.

The hypothesis is rejected, with a path coefficient of 0.442, t-value of 6.406, and p-value of 0.000. This reveals the strongest significant positive effect, confirming that higher automation levels via AGVs, ASCs, and TOS dramatically improve throughput, reduce turnaround time, and enhance cost efficiency. Automation enables 24/7 operations and minimizes human error, directly addressing congestion and dwell time inefficiencies (Harbi, 2021; Alavi-Borazjani et al., 2025). Stickler (2024) and Ayantoyinbo (2015) affirm automation’s role in productivity gains, while Iberahim et al. (2024) link it to faster clearance. In Nigerian context, automation counters manual bottlenecks, making it the most impactful digitization component.

CONCLUSION

In conclusion, this study revealed that Digital Cargo Tracking Systems and Port Automation Level significantly enhance logistics performance in Apapa and Tin Can Island Ports by reducing turnaround time, cargo clearance time, and operational costs. However, Port Community System (PCS) showed no significant effect, likely due to implementation gaps. These findings underscored automation and real-time tracking as critical drivers of maritime efficiency, while highlighting the need to strengthen PCS integration.

Recommendations

i. To enhance Digital Cargo Tracking Systems, NPA and NCS should expand GPS/RFID infrastructure, mandate ECTS adoption, and integrate with NICIS II for seamless real-time visibility and faster clearance.

ii. To strengthen Port Community System (PCS), stakeholders must invest in full interoperability, staff training, and legacy system upgrades to achieve significant performance gains.

iii. To maximize Port Automation Level, terminal operators should accelerate Automated Guided Vehicles (AGVs) and Automated Stacking Cranes (ASCs) deployment, supported by government incentives and public-private partnerships to scale 24/7 automated operations and reduce dwell times below global benchmarks.

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