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Digital and Ai-Driven Logistics in Nigeria's Maritime Supply Chain: Adoption, Barriers, and Performance Outcomes

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A B S T R A C T

The integration of digital and artificial intelligence (AI) technologies is fundamentally reshaping global maritime logistics, offering a pathway to enhanced efficiency, resilience, and competitiveness. Within the context of Nigeria, a nation whose economic fortunes are deeply intertwined with the performance of its seaports, the adoption of these advanced logistics solutions presents both a critical opportunity and a complex challenge. This study investigates the current state of adoption, the prevailing barriers, and the resultant performance outcomes of digital and AI-driven logistics within Nigeria's maritime supply chain. Employing a rigorous secondary data analysis methodology, this research synthesizes evidence from a wide array of sources, including recent academic literature by Nigerian scholars, official performance reports from the Nigerian Ports Authority (NPA), policy documents, and international trade facilitation reports from bodies such as the United Nations Conference on Trade and Development (UNCTAD). The analysis is framed through the integrated lens of the Technology-Organization-Environment (TOE) framework and Institutional Theory, providing a multi-faceted understanding of the adoption dynamics

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INTRODUCTION

The global maritime logistics industry stands at the precipice of a fourth industrial revolution, driven by the convergent forces of digitalization and artificial intelligence. From smart ports leveraging the Internet of Things (IoT) for real-time asset tracking to blockchain platforms ensuring tamper-proof documentation and AI algorithms optimizing vessel schedules and yard operations, these technologies promise unprecedented levels of efficiency, transparency, and resilience (Praxis, 2025). For developing economies endowed with extensive coastlines and reliant on maritime trade, such as Nigeria, this technological shift is not merely an operational upgrade but a strategic imperative for economic survival and growth. Nigeria's maritime sector, facilitated by ports like Apapa, Tin-Can, Onne, and the newly operational Lekki Deep Seaport, serves as the critical artery for over 80% of the nation's international trade by volume. Historically, however, this sector has been beleaguered by chronic inefficiencies, congestion, bureaucratic delays, manual processes, and suboptimal infrastructure, that have eroded competitiveness, inflated logistics costs, and constrained economic potential (Fiberesima & Gabriel, 2025).

In response to these challenges and the compelling global trend, there has been a growing, albeit fragmented, push towards digital transformation within Nigeria's maritime domain. Policy pronouncements, such as the Federal Government's commitment to a National Single Window and the Nigerian Ports Authority's (NPA) "Five-Year Digital Plan," signal high-level intent (Nigerian Ports Authority, 2025). On the ground, initiatives like the electronic truck call-up system (e.g., "Eto" in Lagos) and the deployment of semi-automated gates at certain terminals represent tangible, if incremental, steps towards modernization (Nigerian Ports Authority, 2025). Concurrently, a burgeoning body of academic research by Nigerian scholars has begun to empirically examine the impacts of digitalization on port performance metrics such as revenue, lead time, and operational safety (Fiberesima & Bereiweriso, 2025; Fiberesima & Gabriel, 2025).

Despite this activity, a significant gap persists between policy ambition, scholarly investigation, and widespread, impactful implementation, particularly concerning AI-driven solutions. While existing literature has catalogued general barriers to technology adoption (Ikpogu, 2021) and measured the effects of specific digital tools, there is a scarcity of holistic studies that simultaneously analyze the adoption landscape, diagnose the specific, intertwined barriers to AI integration, and link these to comprehensive performance outcomes within the unique institutional and operational context of Nigeria. Furthermore, many analyses lack a strong theoretical underpinning that can explain *why* certain adoption patterns and barriers emerge.

This study, therefore, seeks to address these gaps. Its primary objective is to provide a comprehensive, theoretically-informed analysis of digital and AI-driven logistics in Nigeria's maritime supply chain.
Specifically, it aims to:

(1) assess the current level and nature of adoption of these technologies;
(2) identify and critically analyze the key barriers impeding their deeper integration; and
(3) evaluate the documented and potential performance outcomes associated with their use. To achieve this, the study employs a secondary data analysis approach, synthesizing findings from published academic research, official industry reports, and policy documents. The analysis is guided by an integrated theoretical framework combining the Technology-Organization-Environment (TOE) model and Institutional Theory, offering a robust lens to decipher the complex interplay of factors at play. The significance of this research lies in its potential to inform more effective, context-sensitive strategies for policymakers, port managers, and technology providers, ultimately contributing to a more efficient, competitive, and resilient Nigerian maritime sector.

LITERATURE RIVIEW

The Digital and AI Transformation of Global Maritime Logistics

The digital transformation of maritime logistics, often conceptualized as the evolution towards "Smart Ports" or "Port 4.0," encompasses a suite of interconnected technologies. These include foundational digital platforms like Port Community Systems (PCS) that enable electronic data interchange among stakeholders, and Internet of Things (IoT) sensors that provide real-time visibility into the location, condition, and security of cargo and assets (Praxis, 2025). Building upon this digital layer, advanced analytics and Artificial Intelligence (AI) introduce predictive and prescriptive capabilities. AI applications in ports range from machine learning models that forecast vessel arrival times and cargo volumes to optimize berth allocation, to computer vision systems that automate container code recognition and damage inspection, and even to the experimental use of autonomous guided vehicles (AGVs) for yard operations.

Globally, the adoption of these technologies has been linked to dramatic improvements in port performance. Key benefits documented in international literature include significant reductions in vessel turnaround time and cargo dwell time, enhanced terminal throughput capacity, improved safety and security, lower operational costs, and increased customer satisfaction. The COVID-19 pandemic acted as a potent accelerant, underscoring the vulnerability of manual, paper-based processes and forcing a rapid adoption of contactless, digital solutions to maintain supply chain continuity (Fiberesima & Gabriel, 2025). This global context sets a performance benchmark against which Nigeria's progress must be measured.

The Nigerian Context: Adoption and Empirical Evidence

Within Nigeria, scholarly research has begun to quantify the impact of digitalization. Studies have moved from purely conceptual discussions to empirical analyses using data from port operators, shipping companies, and regulatory agencies. For instance, Fiberesima, Bereiweriso et al. (2025) found that automated demand planning, warehouse automation, and transport automation have a statistically significant and positive effect on the revenue generation of Nigerian seaports (Fiberesima & Bereiweriso, 2025). In a related study, Fiberesima and Gabriel (2025) applied the TOE framework to demonstrate a strong positive association between the same digitalization dimensions and reduced lead time in seaports, providing a theoretical anchor for understanding these relationships (Fiberesima & Gabriel, 2025).

Focusing on logistics service providers, Christian et al. (2024) established a significant correlation between the adoption of AI, transportation technology, and warehouse automation with the on-time delivery performance of shipping companies in South-West Nigeria (Christian et al., 2024). These studies provide compelling evidence that where digital technologies are adopted, they yield tangible benefits. However, they also frequently note the limitations of current adoption levels. The research by Adelaja, Olayemi, and Falola (2021) is frequently cited for its early identification of the dual narrative of "challenges and prospects," highlighting the gap between technological potential and ground-level reality (Adelaja et al., 2021).

Beyond academic research, official reports from the NPA provide a macro-level view. The Authority's 2025 report highlights "digital platform expansions" and specific initiatives like the Electronic Call-Up System at Onne Port as contributors to recorded improvements in operational metrics, including an 18.9% increase in total container traffic and an 8.4% rise in vessel calls (Nigerian Ports Authority, 2025). These figures, while impressive, often represent outcomes from point solutions rather than a fully integrated, AI-driven logistics ecosystem.

Barriers to Adoption: A Multi-Layered Challenge

The slower-than-desired pace of advanced technology adoption in Nigeria's maritime sector is attributable to a complex web of barriers, which scholarly work has started to delineate. Ikpogu's (2021) qualitative study with industry stakeholders identified 16 thematic barriers, categorized into issues of technology standards, adoption hurdles, acceptance factors, resource needs, and linkage to national development (Ikpogu, 2021). Synthesizing this and other literature, barriers can be conceptualized across four interconnected levels:

1. **Technological & Infrastructural:** This includes unreliable electricity supply, inadequate broadband internet connectivity (especially for data-intensive AI applications), and the high cost of acquiring and maintaining advanced hardware and software. The absence of a robust, integrated national digital infrastructure forms a critical bottleneck.
2. **Organizational & Human Capital:** Within port authorities, terminal operators, and shipping companies, barriers include a lack of digital literacy and technical skills among the workforce, resistance to change from employees and middle management, and a shortage of strategic

vision and change management leadership capable of driving digital transformation.

3. **Economic & Financial:** The high initial capital investment required for technologies like AI and IoT is a major deterrent, particularly for smaller players. This is compounded by uncertain return-on-investment calculations in a volatile economic environment and persistent foreign exchange challenges that make importing technology expensive.
4. **Regulatory & Institutional:** The maritime sector is governed by a multitude of agencies (NPA, NIMASA, Customs, etc.), often with overlapping mandates and disparate, sometimes analogue, procedures. The lack of a fully implemented, mandatory national single window creates data silos and interoperability issues. Furthermore, outdated legislation and a slow, bureaucratic procurement process stifle innovation.

Theoretical Framework: Integrating TOE and Institutional Theory

To systematically analyze the adoption phenomena, this study employs an integrated theoretical framework combining the Technology-Organization-Environment (TOE) framework and Institutional Theory.

The **TOE framework** posits that the adoption of an innovation is influenced by three contexts: the Technological context (the available technologies and their characteristics), the Organizational context (the firm's size, structure, resources, and culture), and the Environmental context (the industry structure, regulatory landscape, and competitive pressures) (Fiberesima & Gabriel, 2025). This framework is particularly apt for the Nigerian maritime sector, as it allows for a structured examination of how factors like the availability of AI solutions (Technology), the readiness of port organizations (Organization), and government policy or competitor actions (Environment) jointly shape adoption decisions.

Institutional Theory complements the TOE framework by explaining how organizations are influenced by external pressures to conform to established norms, rules, and beliefs, a process known as isomorphism. DiMaggio and Powell (1983) identified three mechanisms: **coercive isomorphism** (pressure from regulators, e.g., mandatory use of a new electronic system), **mimetic isomorphism** (imitating successful competitors, e.g., adopting a technology because a rival port has), and **normative isomorphism** (pressure from professional networks and standards, e.g., adopting global port best practices). In Nigeria, coercive pressures from the NPA or Ministry of Marine and Blue Economy are likely strong drivers for basic digitalization, while mimetic pressures may explain the spread of certain technologies among terminal operators.

By integrating these two perspectives, this study develops a more nuanced analytical lens. It proposes that the adoption of digital and AI-driven logistics in Nigeria is not merely a rational, efficiency-driven calculation (as TOE might emphasize) but is also profoundly shaped by the need to gain legitimacy within a complex institutional field comprising government, international partners, and

the global maritime community. This integrated framework guides the analysis of secondary data in the subsequent sections.

METHODOLOGY

This study adopts a qualitative secondary data analysis research design. This approach is deemed appropriate as it allows for the synthesis of existing knowledge from multiple sources to build a comprehensive, holistic understanding of a complex phenomenon, in this case, the adoption of digital and AI technologies in Nigeria's maritime supply chain. The methodology is non-empirical in the primary data collection sense but involves systematic gathering, evaluation, and integration of previously published or publicly available data.

Data Sources: Secondary data was collected from three main categories of sources:

1. Academic Literature: Peer-reviewed journal articles, conference proceedings, and doctoral dissertations by Nigerian researchers and international scholars focusing on Nigeria. Key search terms included "digitalization," "artificial intelligence," "maritime logistics," "port performance," "Nigeria," "adoption barriers," "TOE framework," and "smart port." Databases and platforms such as Google Scholar, ResearchGate, and institutional repositories were searched for works published between 2020 and 2025 to ensure relevance.
2. Industry and Government Reports: Official publications from relevant Nigerian agencies, primarily the Nigerian Ports Authority (NPA) (Nigerian Ports Authority, 2025) and the Nigerian Shippers' Council (NSC). Also included were policy documents, strategic plans (e.g., the NPA's Digital Plan), and performance review reports.
3. International Reports: Publications from global organizations like the United Nations Conference on Trade and Development (UNCTAD), particularly their reports on digital and sustainable trade facilitation which provide a comparative global context (UNCTAD, 2023).

Data Analysis Procedure: The collected data was subjected to a thematic content analysis.

This involved:

- Familiarization: Repeated reading of all sourced materials to gain a deep understanding.
- Coding: Generating initial codes based on the research objectives (e.g., "types of AI adopted," "barrier - infrastructure," "outcome - efficiency gain").
- Theme Development: Collating codes into potential themes that captured broader patterns, such as "Drivers of Adoption," "Layers of Barriers," and "Spectrum of Performance Outcomes."
- Reviewing and Defining Themes: Refining the themes to ensure they accurately represented the data set and clearly addressed the research questions.

- Theoretical Integration: Mapping the developed themes onto the constructs of the integrated TOE and Institutional Theory framework to provide an explanatory analysis.

Limitations: The reliance on secondary data imposes certain limitations. The analysis is constrained by the scope, quality, and availability of existing studies and reports. There may be a publication bias towards successful initiatives, while failures or stalled projects might be underreported. Furthermore, the rapidly evolving technology landscape means some information may become dated quickly. Nonetheless, by triangulating data from academic, industry, and international sources, this study aims to construct a robust and timely evidence-based analysis.

Analysis and Findings

1. State of Adoption: From Digital Foundations to AI Frontiers

The analysis reveals a stratified adoption landscape within Nigeria's maritime supply chain. Adoption is most advanced at the digital foundation layer. The implementation of the electronic truck call-up system (e.g., "Eto" in Lagos and its recent rollout in Onne) is a flagship example of using a digital platform to tackle the perennial problem of congestion and arbitrage (Nigerian Ports Authority, 2025). Similarly, various port terminals have deployed semi-automated gate systems, RFID for cargo tracking, and electronic documentation portals. These efforts are largely driven by coercive isomorphism (regulatory push from NPA) and mimetic isomorphism (copying solutions that have reduced queues at adjacent terminals).

The adoption of core AI-driven applications, however, remains in a nascent or pilot phase. Evidence suggests use cases are isolated and experimental. Examples include the potential use of basic data analytics for reporting (as seen in NPA performance reports) and exploratory discussions or small-scale pilots involving predictive analytics for equipment maintenance or cargo volume forecasting. There is little evidence of widespread deployment of machine learning for dynamic resource allocation, computer vision for fully automated inspection, or autonomous vehicles. The technological context is constrained by cost and complexity, while the organizational context often lacks the data maturity and in-house expertise to develop and manage such systems.

2. A Diagnostic of Barriers: The TOE-Institutional Perspective

The barriers to deeper AI integration are profound and mutually reinforcing, as analyzed through the integrated theoretical framework.

Technological Context Barriers: The high perceived cost and complexity of AI solutions are paramount. Many stakeholders perceive AI as a "black box" requiring significant investment with an uncertain, long-term ROI. Furthermore, the foundational digital infrastructure, stable high-speed internet across port premises and reliable power, is often lacking, making the deployment of data-intensive AI applications impractical (Praxis, 2025).

- Organizational Context Barriers: Perhaps the most critical barrier is the human capital deficit. There is an acute shortage of data scientists, AI specialists, and even digitally literate mid-level managers within maritime organizations (Ikpogu, 2021). This is compounded by organizational cultures that are often hierarchical and risk-averse, resistant to the data-driven, agile decision-making that AI enables. Leadership may lack the strategic vision to champion AI transformation beyond superficial digitalization.
- Environmental Context Barriers: The regulatory environment, while improving, remains complex. Multiple agencies requiring different data submissions in different formats create interoperability nightmares that hinder the integrated data ecosystems AI thrives on. While coercive pressure drives basic digital compliance, it has not yet been effectively leveraged to mandate data-sharing standards or AI readiness. Economically, high inflation and foreign exchange volatility make long-term technology investments fraught with financial risk.

From an institutional theory perspective, the normative pressures from global "smart port" benchmarks are growing, creating a pull factor. However, the coercive pressures have not yet evolved to specifically encourage AI adoption, and mimetic pressures are weak because there are few local "success models" of AI implementation to imitate.

3. Performance Outcomes: Documented Gains and Potential

Where adoption has occurred, the performance outcomes align with global evidence, though they are often attributed to digitalization broadly rather than AI specifically.

1. Operational Efficiency: The most direct outcome is improved efficiency. The electronic call-up system has demonstrably reduced truck turnaround times and queue-related congestion at port gates. Studies link automation in inventory management and transport to reduced cargo lead times (Fiberesima & Gabriel, 2025). The NPA report cites a 16.2% increase in total cargo throughput and an 18.9% rise in container traffic, attributing this partly to digital platform expansions (Nigerian Ports Authority, 2025).

2. Economic Performance: Enhanced efficiency translates to economic gains. Fiberesima et al. (2025) found a significant positive effect of digitalization on seaport revenue generation (Fiberesima & Bereiweriso, 2025). For shipping companies, Christian et al. (2024) correlated technology adoption with improved on-time delivery, a key service quality metric that can command price premiums and customer loyalty (Christian et al., 2024).

3. Strategic and Regulatory Outcomes: Digitalization supports strategic goals like transparency and compliance. The move towards a National Single Window, facilitated by digital platforms, aims to reduce corruption and streamline customs clearance. Furthermore, digital records and IoT tracking enhance cargo security and safety, meeting international regulatory requirements.

The potential performance outcomes from fuller AI adoption are even more significant but remain largely hypothetical in the Nigerian context. They include predictive maintenance to reduce equipment downtime, AI-optimized

stowage plans to maximize vessel and yard space, and dynamic pricing models for port services.

RESULT AND DISCUSSION

The findings present a clear picture: Nigeria's maritime sector is on a digitalization journey, but it remains in the early stages, with a chasm separating the current state from a truly AI-driven future. The adoption pattern is characteristic of many developing economies, driven first by the need to solve acute, visible problems (congestion, documentation delays) through digital tools, with the more transformative, integrative potential of AI awaiting a more conducive ecosystem.

The integrated TOE and Institutional Theory framework proves highly effective in explaining this stalled progress. It moves the analysis beyond a simple checklist of barriers to reveal their systemic nature. For instance, the **human capital gap (Organizational context)** is not just a training issue; it is sustained by a lack of **normative isomorphism** from professional bodies setting AI competency standards for port managers, and is exacerbated by an **Environmental context** where the national education system does not produce enough AI talent. Similarly, the high cost of technology (**Technological context**) is magnified by the **economic volatility (Environmental context)** and the lack of **coercive** government incentives like tax breaks for AI investments in critical infrastructure.

The discussion must also engage with the seeming paradox presented by the findings: documented efficiency gains exist alongside persistent, deep-rooted barriers. This suggests that the gains achieved so far are largely "low-hanging fruit" from automating manual, paper-based processes. These successes are necessary but insufficient for leapfrogging to global competitiveness. The next tier of performance improvements, enabled by AI, requires tackling the harder, systemic barriers related to data governance, institutional collaboration, and strategic human capital development.

This research aligns with and extends the work of earlier scholars. It confirms the barriers identified by Ikpogu (2021) and Adelaja et al. (2021) but frames them within a stronger theoretical structure that explains their persistence. It also builds on the positive performance correlations found by Fiberesima et al. (2025) and Christian et al. (2024) by contextualizing them as outcomes of a specific, limited phase of adoption, thereby tempering over-optimism with a realistic assessment of the journey ahead.

Implications for Policy and Practice:

1. **For Policymakers (NPA, Ministry of Marine & Blue Economy):** Policy must evolve from mandating specific digital tools to creating an enabling ecosystem for innovation. This includes:
   - **Developing a National Maritime Data Strategy** that mandates interoperability standards and secure data-sharing protocols among agencies and operators.
   - Using **coercive isomorphism** strategically by offering incentives (e.g., reduced port dues) for terminals that pilot and scale AI solutions.

- **Partnering with academia and tech hubs** to fund applied AI research for port-specific challenges and create talent pipelines.

2. **For Port Authorities and Terminal Operators:** Leadership must foster an **AI-ready organizational context**. This involves: (a) Appointing Chief Digital/Data Officers with strategic authority. (b) Investing in upskilling programmes to build internal "translator" capabilities—professionals who understand both maritime operations and data science. (c) Starting with focused, high-impact pilot projects (e.g., AI for predictive yard congestion) to build internal confidence and demonstrate ROI.
3. **For Technology Providers and Investors:** Solutions must be designed for the Nigerian context: affordable, modular, cloud-based to circumvent infrastructure limits, and accompanied by strong local support and capacity-building. Public-Private Partnership (PPP) models should be explored to share the financial risk and reward of large-scale AI deployments.

Limitations and Future Research:

This study's limitation is its reliance on secondary data. Future research should employ primary mixed-methods approaches. Quantitative surveys could measure the precise correlation between specific AI capabilities and performance metrics across a larger sample. Qualitative case studies of successful (or failed) technology implementations within Nigerian ports could yield rich insights into the micro-processes of change management and institutional negotiation that this macro-level analysis could not capture.

CONCLUSIONS AND RECOMMENDATIONS

This study has provided a comprehensive, theoretically-grounded analysis of digital and AI-driven logistics in Nigeria's maritime supply chain. It concludes that while the sector has made commendable strides in laying a digital foundation, driven largely by institutional pressures to address operational inefficiencies, the adoption of transformative AI technologies remains minimal. The barriers are systemic, spanning inadequate technological infrastructure, a profound organizational skills gap, financial constraints, and a complex regulatory environment. These barriers are best understood as interacting elements within the Technology-Organization-Environment contexts, further shaped by the institutional forces of coercion, imitation, and norm-setting.

The performance gains realized from initial digitalization are real and valuable, contributing to improved efficiency, revenue, and service quality. They provide a proof-of-concept and a platform upon which to build. However, they represent the first chapter of a longer story. To write the next chapter, where Nigerian ports evolve from being digitally assisted to being intelligently autonomous, requires a paradigm shift in strategy. The focus must expand from procuring technology to cultivating an entire innovation ecosystem: building data assets, nurturing human capital, simplifying institutions, and fostering collaboration.

The journey towards AI-driven maritime logistics is not merely a technological upgrade for Nigeria; it is a critical component of national economic strategy, essential for reducing the cost of trade, enhancing export competitiveness, and securing a leading role within the African Continental Free Trade Area (AfCFTA). By acknowledging the complexity of the adoption landscape detailed in this paper and acting on the integrated recommendations, stakeholders can co-create a future where Nigeria's maritime sector is not just a participant in the global digital revolution, but a distinctive and competitive actor on its own terms.

FURTHER STUDY

This study still has limitations so further research is needed on the topic of Digital and AI-Based Maritime Logistics Supply Chain: Adoption, Barriers, and Performance Results

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