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BENEFITS OF ARTIFICIAL INTELLIGENCE IN THE REDUCTION OF PORT CONGESTION: A STUDY OF APAPA WHARF, NIGERIA

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ABSTRACT

Port congestion remains a critical challenge in Nigerian maritime logistics, particularly at Apapa Wharf, the nation's busiest seaport. This study examined the perceived benefits of Artificial Intelligence (AI) in reducing congestion at Apapa Wharf, addressing a significant gap in literature regarding AI applications in African ports using Apapa Wharf as a case study. The research adopted a descriptive survey design with a quantitative approach, targeting 1,161 management staff of the Nigerian Ports Authority, a federal government agency established in 1954 that governs and regulates all ports in Nigeria, at Apapa Wharf. A sample of 297 respondents was determined using Taro Yamane's formula, and 210 valid responses were analyzed using descriptive statistics (mean and standard deviation) and inferential statistics (chi-square test). The findings revealed that respondents strongly agreed on multiple AI benefits, including AI-powered predictive analysis for vessel maintenance forecasting (mean=3.20), Internet of Things integration for real-time monitoring (mean=3.14), AI chatbots for improved customer service (mean=3.22), automated systems reducing turnaround time (mean=3.18), AI-driven Vessel Traffic Systems providing real-time information (mean=3.38), and biometric AI technologies enhancing security access control (mean=3.20). The chi-square test confirmed a statistically significant perceived benefit of AI in reducing congestion ($\chi^2 = 147.50$, $p < 0.05$). The study concluded that AI tools offer substantial benefits for port decongestion and recommended that strategic investment in AI technologies, stakeholder training, and supportive regulatory frameworks.

Keywords: AI, Port Congestion, Apapa Wharf, Maritime Logistics, Predictive Analytics, Real-time Monitoring
JEL Classification: L91, O33, R41, C83

1.0 INTRODUCTION

The maritime transportation sector constitutes the backbone of global trade, with approximately 90% of world trade volume carried by sea (Clark et al 2004; Alam et al, 2020). Seaports serve as critical nodes in international supply chains, functioning as interfaces between maritime and land transport systems. However, port congestion has emerged as a persistent challenge globally, with developing economies experiencing disproportionate impacts due to infrastructural deficiencies and operational inefficiencies (Ndikom & Emeghara, 2012; Nze & Onyemechi, 2018).

Nigeria, as Africa's largest economy and most populous nation, relies heavily on its seaports for international trade. The Apapa Wharf complex in Lagos represents Nigeria's premier port facility, handling over 70% of the nation's import and export cargo (Oyatoye et al., 2011; Ugah, et al 2024). Despite its strategic importance, Apapa Wharf has been plagued by chronic congestion, resulting in significant economic losses, extended vessel turnaround times, increased freight costs, and supply chain disruptions (Godfrey, 2018; Ireje & Sile, 2024).

Traditional approaches to port congestion management, including manual documentation procedures, physical traffic control, and reactive operational adjustments, have proven inadequate in addressing the scale and complexity of congestion challenges (Anagor-Ewuzie, 2022; Somuyiwa et al 2021). This inadequacy has prompted increased interest in technological solutions, particularly Artificial Intelligence (AI), as a strategic tool for enhancing port operational efficiency.

AI encompasses computational systems capable of performing tasks that typically require human intelligence, including learning, reasoning, problem-solving, and decision-making (Jackson, 2019; Lu, 2019). Within port operations, AI applications include predictive analytics for demand forecasting, machine learning algorithms for route optimization, computer vision for container tracking, and natural language processing for stakeholder communication (Chui et al 2018; Lee et al., 2020).

The potential benefits of AI in port operations are substantial. AI can optimize cargo handling processes, reduce waiting times, improve vessel turnaround efficiency, enhance security protocols, and facilitate real-time decision-making (Darendeli et al., 2021; Ma et al., 2020). Moreover, AI-driven systems can integrate data from multiple sources, including Internet of Things (IoT)

sensors, Global Positioning Systems, and automated identification systems, to provide comprehensive situational awareness (Cammin et al., 2020; El Mekkaoui et al., 2020).

Despite growing recognition of AI's potential, empirical research on AI benefits in African port contexts remains limited. Most existing studies have focused on developed economies or broader logistics applications, leaving a significant gap in understanding how AI can address congestion challenges in resource-constrained environments (Bolat et al., 2020; Loh et al., 2017). This study addresses this gap by investigating the perceived benefits of AI for congestion management at Apapa Wharf.

The specific objective of this study was to establish the various benefits of AI for effective decongestion at Apapa Wharf. The research question guiding the investigation was: What are the various benefits of AI for effective decongestion at Apapa Wharf? The corresponding hypothesis tested was: There are no significant benefits of AI for effective decongestion at Apapa Wharf.

The significance of this study extends to multiple stakeholders. For port authorities, the findings provide operational insights into AI applications that can enhance planning, resource allocation, and cargo management. For government agencies, the research offers evidence-based information for policy formulation regarding technology adoption in maritime infrastructure. For the academic community, the study contributes to the growing body of knowledge on AI-driven logistics in emerging economies.

2.0 LITERATURE REVIEW

2.1 Conceptual Framework

2.1.1 Concept of Seaport Operations

Seaports are complex entities that provide essential services for international trade, including cargo handling, vessel services, infrastructure provision, and security management (Park & Seo, 2016; Shan et al 2014). According to the United Nations Conference on Trade and Development, seaports function as interfaces between multiple transport modes, serving as multifunctional markets and industrial areas where goods are not only in transit but also sorted, manufactured, and distributed (Godfrey, 2018).

The efficiency of seaport operations directly affects economic survival and viability of nations (Jouili, 2016; Sharapiyeva et al 2019). Nigerian seaports, particularly Apapa Wharf, are increasingly import-dependent, with cargo throughput statistics showing significant growth in the

post-concession era (Russel & Noving,t6tyty 2018; Ndikom 2013). The period between 2006 and 2012, cargo throughput increased from 46,150,518 metric tons to 77,104,738 metric tons, representing a 67% increase (Laogbebikan et al, 2013).

2.1.2 Concept of Port Congestion

Port congestion refers to obstacles in shipyards or wharves resulting from excessive shipment volumes that hinder free flow of cargo (Ndikom & Emeghara, 2012). Congestion manifests in various forms, including recurrent congestion at regular peak times, non-recurrent congestion due to vehicle breakdowns, and pre-congestion representing borderline conditions before full congestion occurs (Iroham et al., 2019).

In the Nigerian context, seaport congestion became evident from the year 2000, with attendant challenges including delays, sharp practices, and operational inefficiencies (Somuyiwa et al., 2021; Ndikom, 2006). Despite port reforms and concessioning implemented in 2006, logistics processes at Nigerian seaports have yet to achieve the targeted rapid cargo delivery within 24 hours (Adepoju, 2021; Osadume & Edih, 2020).

2.1.3 AI in Port Operations

AI is defined as the ability of computers to accomplish tasks that normally require human intelligence, including decision-making, problem-solving, pattern recognition, and language understanding (Jackson, 2019; Russell & Norvig, 2018). AI has progressed significantly, with applications across multiple fields including healthcare, finance, education, and autonomous systems (Rasheed et al., 2024; Rashid & Kausik, 2024).

Within port operations, AI applications can be categorized into several domains. Predictive analytics powered by machine learning can forecast vessel arrival times, maintenance needs, and cargo volumes (Chargui et al., 2021; Yang & Chang, 2020). Computer vision systems can automate container identification, tracking, and security monitoring (Singla et al., 2024). Natural language processing enables automated customer service through chatbots and documentation processing (Yenduri et al., 2024). Optimization algorithms can enhance berth allocation, crane scheduling, and route planning (Michail et al., 2015; Lee et al., 2020).

2.2 Theoretical Framework

2.2.1 Queuing theory

The queuing theory, originated by Danish mathematician Agner Krarup Erlang in the early 1900s, mathematically examines how congestion and delays occur (Oyatoye et al., 2011). The theory analyzes every aspect of waiting in queues, including number of servers, system places, and customer characteristics. Queuing theory has been applied to port congestion problems, providing a standardized method for port management to control movement of shipments, cargoes, and international merchandise. The theory operates on the "first come, first served" principle in conducting port supervision of merchandise at berths.

2.2.2 Technological Acceptance Model (TAM)

TAM, established by Ajzen and Fisbein in 1980 and developed by Davis (1980) and reformulated in 2022, predicts and explains consumer adoption of information technology. TAM contends that user acceptance of novel systems is determined by users' intention to use, which is impacted by users' perceptions of the system's perceived usefulness and usability (Venkatasubramanian, 2019; Na et al., 2022).

2.2.3 Resource-Based Theory

Resource-based theory, pioneered by Edith Penrose in the years 1959. The term was officially coined by Birger Wernerfelt in 1984. RBT posits that unique resources are the main sources of competitive advantage and organizational performance (Baradwaj, 2020; Wu et al., 2016). Teece (1997) developed the concept of dynamic capabilities, his work focused on the ability of the firm to reconfigure and build competence that will adapt to a rapidly changing environment. Grant (1991) further emphasized the relationship between resources, capability and profitability to create a framework that enables strategy formulation using internal resources. In the context of AI adoption, technological resources including IT capabilities, IT infrastructure, and IT human resources represent valuable organizational assets that can enhance port performance.

2.3 Empirical Review

Several studies have examined technology adoption in port operations. Nwoloziri et al. (2021) evaluated the impact of effective cargo distribution on the Nigerian economy, finding that cargo distribution significantly influences economic growth. Godfrey (2018) investigated Onne Seaport's

post-concession performance, revealing inconsistent performance trends. Ibeawuchi and Chinedum (2018) examined port congestion determinants in five African ports, identifying poor planning, regulation, capacity, and efficiency as primary causes.

Regarding AI and technology benefits, Chui et al. (2018) documented how AI can automate routine tasks, improve decision-making, and enhance operational efficiency across industries. Lee et al. (2020) demonstrated how machine learning can predict ship berthing velocity risk ranges, enabling proactive safety measures. Ma et al. (2020) illustrated how AI applications in autonomous vehicles can optimize transportation systems. Michail et al. (2015) showed how AI-based fault detection can reduce computational costs while improving industrial system reliability.

In the maritime context, Darendeli et al. (2021) applied machine learning methods to container demand forecasting, achieving improved accuracy compared to traditional methods. Chargui et al. (2021) developed predictive models for quay crane productivity, enabling better schedule planning. Cammin et al. (2020) demonstrated how real-time data can reduce air emissions in maritime ports through optimized operations.

2.4 Research Gap

Despite existing literature on technology adoption in port operations, several gaps remain. First, most research on AI applications in logistics has focused on broader supply chain optimization rather than specific port congestion challenges. Second, empirical studies on AI benefits in African port contexts are scarce, with most evidence derived from developed economies. Third, there is limited research on how AI can be integrated into strategic decision-making processes for congestion management specifically at Apapa Wharf. This study addresses these gaps by providing empirical evidence on AI benefits for port decongestion in a Nigerian context.

3.0 MATERIALS AND METHODS

3.1 Research Design

This study adopted a descriptive research design using quantitative methodology. Descriptive study design measures outcomes and exposures in the study population (Majid, 2018; Williams, 2011). The descriptive survey research method was employed, which is appropriate when researchers are interested in attitudes, perceptions, and behaviors of people toward variables or phenomena (Obaze & Onosu, 2009; Oberiri, 2017).

3.2 Area of Study

The research was conducted at the Nigerian Ports Authority (NPA), an agency that oversees and regulates all ports in Nigeria, Apapa Wharf complex in Lagos State, Nigeria. Apapa Wharf represents Nigeria's largest and busiest seaport, handling the majority of the nation's international trade cargo.

3.3 Population of the Study

The target population comprised all management staff of the NPA at Apapa Wharf, resulting to 1,161 employees. The population included managers, supervisors, directors, and other management-level personnel directly involved in port operations and decision-making (Broeck et al 2013; Polit & Beck, 2004).

3.4 Sample Size and Sampling Technique

Sample size was determined using the Taro Yamane formula (Yamane, 2021):

$n = N / (1 + N(e)^2)$

Where n = sample size, N = population (1,161), and e = error margin (0.05)

$n = 1,161 / (1 + 1,161 \times 0.0025) = 1,161 / 3.9025 = 297$

A purposive sampling technique of non-probability sampling was adopted. This technique allowed the researcher to select respondents based on specific criteria, ensuring that only management staff with relevant knowledge of port operations were included (Blumberg, et al, 2011).

3.5 Instrument for Data Collection

The instrument for data collection was a structured questionnaire containing 30 items. The questionnaire was divided into two sections: Section A covered demographic data (age, religion, gender, length of service, educational background, marital status), while Section B contained items addressing the research objectives using a 4-point Likert scale (Strongly Agree = 4, Agreed = 3, Disagreed = 2, Strongly Disagree = 1) (Blumberg et al., 2011; James, 2014).

3.6 Procedure for Data Collection

The questionnaire was administered electronically to respondents through online platforms. Research assistants were available to clarify questions and ensure all distributed questionnaires were duly completed and returned. A response rate of 97.5% was achieved, with 210 valid responses obtained from the 297 targeted sample.

3.7 Techniques for Data Analysis

Data were analyzed using SPSS version 21. Descriptive statistics (mean and standard deviation) were employed to analyze responses to research questions, with a benchmark mean of 2.50 for acceptance. Inferential statistics (chi-square test) were used to test the hypothesis at 0.05 significance level (Oberiri, 2017; Howell, 2013).

4.0 DATA AND DISCUSSIONS

4.1 Demographic Characteristics of Respondents

Analysis of demographic data revealed that 50.5% of respondents were aged 20-30 years, 38.1% were aged 31-40 years, and 11.4% were 41 years and above. Male respondents constituted 67.1% while females represented 32.9%. Regarding educational qualification, 31% had NCE/OND, 41.4% held BSC/HND, 23.8% possessed MSc, and 3.8% had PhD. Married respondents comprised 65.2%, single respondents 32.9%, and others 1.9%.

4.2 Perceived Benefits of AI for Congestion Management

Table 1 presents the mean and standard deviation of respondents' perceptions regarding AI benefits for congestion management at Apapa Wharf.

Table 1: Various Benefits of AI for Effective Congestion at Apapa Wharf

Description of Items	Mean Statistic	Mean Std.Error	Std Dev. Statistic
AI-powered predictive analysis are utilized to forecast vessel maintenance needs, prevent costly breakdown	3.2000	0.12778	0.90351
Integration of Internet of Thing has enhanced real time monitoring of port operations	3.1400	0.11432	0.80837

AI Chatbot will improve instant response and reduce the workload on human operations and will improve customer satisfaction and operation efficiency	3.2200	0.12219	0.86402
The adoption of automated system will reduce turnaround time labour requirement and enhancing port productivity	3.1800	0.12352	0.87342
The leveraging of AI-driven VTS will provide real-time information and enhancing maritime domain awareness	3.3800	0.10258	0.72534
The adoption of AI technologies for biometric will enhance security and access control for port operations and facilities efficient access management	3.2000	0.12778	0.90351

Source: Field Computation (2025)

All six items in the table 1 had mean scores above the 2.50 benchmark, indicating strong agreement among respondents regarding AI benefits. The highest-rated benefit was AI-driven Vessel Traffic Systems (VTS) providing real-time information and enhancing maritime domain awareness (mean = 3.38, SD = 0.725). This finding aligns with Nze & Onyemechi (2018), who noted that intelligent transport systems based on AI can improve traffic flow management in real time.

AI chatbots for improved customer service (mean = 3.22, SD = 0.864) and predictive analysis for vessel maintenance (mean = 3.20, SD = 0.904) also received strong endorsement. These findings support Lee et al. (2020), who demonstrated that AI-powered chatbots provide quick and accurate responses, ensuring 24/7 availability of support and improving customer satisfaction.

Integration of IoT for real-time monitoring (mean = 3.14, SD = 0.808) and automated systems for reduced turnaround time (mean = 3.18, SD = 0.873) were similarly recognized as significant benefits. This corroborates Chui et al. (2018), who documented how AI can automate routine tasks and improve operational efficiency.

4.3 Hypothesis Testing

Hypothesis Two: There are no significant benefits of AI for effective decongestion at Apapa Wharf.

Table 2: Chi-square Test of Perceived Benefits of AI for Effective Congestion Control at Apapa Wharf

Response	Observed Frequency (O)	Expected Frequency (E)	O - E	$(O - E)^2$	$(O - E)^2 / E$
Agreed	193	105	88	7744	73.75
Disagreed	17	105	-88	7744	73.75
Total	210	210	-	-	147.50

Source: Author's Computation (2025)

Test Summary:

- Chi-square (χ^2) = 147.50
- Degrees of Freedom = 1
- Significance Level = 0.05
- Critical Value = 3.841

Since the calculated chi-square value (147.50) exceeds the critical value (3.841) at 0.05 significance level with 1 degree of freedom, the null hypothesis is rejected. Therefore, there is a significant perceived benefit of AI in reducing congestion at Apapa Wharf.

4.4 Discussion of Findings

The finding of significant AI benefits for port decongestion aligns with existing literature. AI's ability to analyze large volumes of data and identify patterns enables more accurate demand forecasting and proactive congestion management (Yang & Chang, 2020; Darendeli et al., 2021). The recognition of AI chatbots as beneficial supports Lee et al. (2020), who found that AI-powered customer service tools improve response times and customer satisfaction while reducing human workload.

The endorsement of predictive analysis for vessel maintenance aligns with Michail et al. (2015), who demonstrated that AI-based fault detection reduces computational costs while improving system reliability. In the port context, predictive maintenance can prevent costly breakdowns that contribute to congestion through equipment failure.

The finding regarding IoT integration for real-time monitoring supports Cammin et al. (2020) and El Mekkaoui et al. (2020), who showed how real-time data can optimize port operations and reduce environmental impact. Real-time visibility enables stakeholders to make informed decisions and respond quickly to emerging congestion situations.

The high rating of AI-driven Vessel Traffic Systems reflects the importance of maritime domain awareness for congestion management. As noted by Nze & Onyemechi (2018), AI-enabled traffic management systems can analyze patterns, optimize signal timing, and identify potential hazards in real time.

The significant chi-square result ($\chi^2 = 147.50$) provides strong statistical evidence that port stakeholders recognize AI's potential to address congestion challenges. This finding is consistent with global trends documented by Chui et al. (2018) and Manyika (2022), who noted that AI is transforming industries by optimizing efficiency and enabling data-driven decision-making.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study investigated the perceived benefits of AI in mitigating congestion at Apapa Wharf, Nigeria's largest seaport. The findings demonstrate that stakeholders recognize multiple significant benefits of AI applications for port decongestion. Specifically, AI-driven Vessel Traffic Systems for real-time information and maritime domain awareness received the highest endorsement, followed by AI chatbots for customer service, predictive analysis for vessel maintenance, automated systems for reduced turnaround time, biometric technologies for security access control, and IoT integration for real-time monitoring.

The statistical analysis confirmed that the perceived benefits of AI for congestion management are significant, leading to rejection of the null hypothesis. This indicates strong stakeholder confidence in AI's potential to enhance operational efficiency, reduce delays, improve customer satisfaction, and optimize resource utilization at Apapa Wharf.

The study concludes that AI tools offer substantial benefits for addressing port congestion challenges. However, realizing these benefits requires strategic investment in AI infrastructure, capacity building for port personnel, and supportive regulatory frameworks. The findings provide empirical evidence that can guide decision-making by port authorities, government agencies, and private sector stakeholders regarding AI adoption in maritime logistics.

5.2 Recommendations

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

a. Investment in AI Technologies: The NPA should prioritize investment in AI-driven Vessel Traffic Systems, predictive analytics platforms, and IoT sensor networks to enhance real-time monitoring and decision-making capabilities at Apapa Wharf.

b. Implementation of AI Chatbots: Port management should deploy AI-powered chatbots to handle customer inquiries, provide real-time information on vessel schedules and cargo status, and reduce the workload on human customer service personnel.

c. Adoption of Automated Systems: Investment in automated cargo handling systems, including automated guided vehicles and smart cranes, should be accelerated to reduce turnaround time and improve port productivity.

d. Integration of Biometric Security: AI-powered biometric access control systems should be implemented to enhance port security while facilitating efficient access management for authorized personnel and vehicles.

e. Capacity Building: Regular training programs should be provided for port staff to develop skills in AI system operation, maintenance, and data interpretation, ensuring maximum utilization of AI technologies.

f. Regulatory Support: Government agencies should develop clear policies and regulatory frameworks that encourage AI adoption while addressing concerns related to data privacy, cybersecurity, and ethical AI use.

5.3 Suggestions for Further Studies

g. Future research should explore the comparative effectiveness of different AI technologies in addressing specific aspects of port congestion.

h. Additionally, longitudinal studies examining the long-term impact of AI implementation on port performance metrics would provide valuable insights.

i. Research investigating the integration of AI with other emerging technologies such as blockchain and digital twins in port operations is also recommended.

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