

# Role of Technological Innovation Adoption in enhancing Pilotage Operations at Onne Port, Nigeria

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**Abstract-** *Technological innovation has become the cornerstone of modern maritime operations, redefining the efficiency, safety, and competitiveness of port systems. However, pilotage operations in many developing ports, including Onne Port, Nigeria, still face inefficiencies due to limited technological adoption. This study examined the role of technological innovation adoption in enhancing pilotage operations at Onne Port, Nigeria. A descriptive research design was adopted, utilizing a well-structured questionnaire administered to 30 port personnel, including Marine Pilots, Vessel Traffic Management and Information System (VTMIS) Officers, and ICT/Technical Staff. Using snowballing and incidental sampling techniques, a sample size of 28 respondents was analyzed through multiple regression analysis. Findings from the regression results revealed that all five predictors Automation of Pilotage Scheduling ( $p = 0.041$ ), Vessel Traffic Management and Information System ( $p = 0.000$ ), Electronic Ship Clearance System ( $p = 0.000$ ), Port Community System ( $p = 0.004$ ), and ICT and Maintenance Support System Efficiency ( $p = 0.001$ ) were statistically significant in explaining variations in pilotage operations. The study concluded that technological innovation adoption significantly enhances pilotage efficiency, safety, and coordination at Onne Port. It was therefore recommended that sustained investment in digital systems, staff training, and ICT infrastructure be prioritized to improve operational performance and global competitiveness.*

**Keywords:** *Technological Innovation, Pilotage Operations, Port Efficiency, Digitalization, Onne Port, Nigeria*

## I. INTRODUCTION

Technological innovation has become the driving force behind transformation in global maritime operations, reshaping the way ports function, compete, and deliver services in an increasingly digitalized economy. In modern port environments, technology adoption is no longer optional it is a critical determinant of efficiency, competitiveness, and sustainability (Notteboom & Haralambides, 2022; UNCTAD, 2023). Ports serve as vital gateways for trade, logistics, and industrial development,

linking nations to global value chains and facilitating the seamless movement of goods and services (Rodrigue & Notteboom, 2020). In this context, pilotage operations, which involve guiding vessels safely into and out of harbours, stand as one of the most crucial components of port safety and navigation management. The integration of advanced technologies into pilotage services has therefore become essential in enhancing precision, minimizing human error, and optimizing turnaround times (Wang et al., 2021).

The role of technological innovation adoption in pilotage operations extends far beyond automation it embodies a paradigm shift towards smarter, safer, and more resilient maritime systems. Emerging technologies such as Global Positioning Systems (GPS), Automatic Identification Systems (AIS), electronic navigation charts (ENCs), and digital pilotage platforms have redefined how pilots communicate, monitor, and manoeuvre vessels (Acciaro et al., 2021; Li & Cullinane, 2022). These innovations enhance situational awareness, reduce risks of collision, and ensure compliance with international maritime safety standards. In Nigeria, where port operations are integral to national economic growth, the efficient adoption of these technologies is indispensable for improving service delivery, reducing delays, and aligning with global maritime best practices (Akinwale & Adesanya, 2023).

Despite the acknowledged importance of technological innovation, the pace of adoption in many Nigerian ports remains relatively slow. Challenges such as inadequate infrastructure, high implementation costs, lack of technical expertise, and resistance to change have hindered the full integration of smart technologies in pilotage and other port operations (Olowokudejo & Ogunsanya, 2022; NPA, 2024). These limitations often result in inefficient vessel handling, operational delays, and safety risks, undermining the competitiveness of

Nigerian ports in regional and international trade. The Onne Port, located in Rivers State, serves as a critical industrial and oil and gas logistics hub; however, its pilotage operations still face operational bottlenecks that can be mitigated through effective technological adoption.

Therefore, this study seeks to explore the role of technological innovation adoption in enhancing pilotage operations at Onne Port, Nigeria. By examining how digital tools, data-driven systems, and navigational technologies influence operational efficiency, safety, and communication within the port environment, this research aims to contribute to the growing discourse on port digitalization in developing economies. Understanding the extent to which technology can improve pilotage operations will not only inform national maritime policy but also provide actionable insights for stakeholders seeking to strengthen Nigeria's position in the global maritime network.

## II. LITERATURE REVIEW

### Technological Innovations in Port Operations

The adoption of technological innovations has significantly reshaped the structure and efficiency of maritime and port operations worldwide. According to Notteboom and Rodrigue (2020), the integration of digital technologies in ports enhances productivity, improves cargo handling, and strengthens navigational safety, ultimately increasing the global competitiveness of maritime nations. The evolution of Port Community Systems (PCS), automation, and digital logistics platforms has enabled seamless communication among port stakeholders, thereby reducing bottlenecks and turnaround times (Ng & Ducruet, 2021). In recent years, ports have increasingly embraced smart technologies such as Internet of Things (IoT) sensors, Artificial Intelligence (AI), and Big Data analytics, which collectively contribute to data-driven decision-making and operational optimization (Acciaro et al., 2021).

The Nigerian port system has recognized the potential of digital transformation in improving service delivery and operational efficiency. According to Akinwale and Adesanya (2023), the introduction of automated systems in port logistics enhances transparency, reduces corruption, and accelerates cargo clearance procedures. However, the

rate of technological adoption remains inconsistent across different Nigerian ports due to infrastructural deficits, funding constraints, and inadequate technical expertise (Olowokudejo & Ogunsanya, 2022). This uneven adoption presents a challenge to achieving harmonized and efficient maritime operations, particularly in pilotage and navigation services.

The integration of digital technology in ports has also played a vital role in promoting maritime safety and environmental sustainability. The International Maritime Organization (IMO, 2022) underscores the significance of adopting navigational aids such as Electronic Chart Display and Information Systems (ECDIS), Automatic Identification Systems (AIS), and Vessel Traffic Services (VTS) in ensuring vessel safety, minimizing human error, and supporting maritime situational awareness. Studies by Li and Cullinane (2022) further confirm that ports employing smart navigation systems experience reduced collision risks and improved vessel routing accuracy. These advancements underscore the importance of technological innovation in improving operational performance and maintaining the safety integrity of port activities.

### Pilotage Operations

Pilotage operations constitute one of the most critical components of maritime navigation and safety management. They involve the guidance of ships through congested waterways and port approaches, where precision, coordination, and situational awareness are paramount. Traditionally, pilotage relied heavily on human expertise and manual observation; however, recent technological innovations have transformed this practice into a data-driven and technology-assisted operation (Wang et al., 2021). The introduction of Portable Pilot Units (PPUs), equipped with real-time navigation charts and GPS tracking, allows pilots to make informed manoeuvring decisions with higher accuracy (Kim et al., 2020). These digital tools provide enhanced visibility of port layouts, tidal conditions, and vessel traffic, thereby improving operational safety and efficiency.

The use of Automatic Identification Systems (AIS) has been particularly instrumental in improving pilotage communication and situational awareness. According to Yang et al. (2021), AIS provides continuous vessel tracking data, enabling pilots and

port control centres to anticipate movements and prevent traffic conflicts. Similarly, Vessel Traffic Management and Information Systems (VTMIS) combine radar, communication, and data analytics to monitor maritime activity, thus facilitating safer navigation and faster decision-making (Gong & Lee, 2019). The deployment of simulation-based pilot training systems has also emerged as an effective means of enhancing the competence of marine pilots, providing realistic practice scenarios for emergency handling and complex manoeuvres (Rahman & Chou, 2022).

The adoption of such technologies at Onne Port remains at a developing stage. According to NPA (2024), while the Nigerian Ports Authority has initiated several modernization efforts including the installation of radar systems and communication networks pilotage operations still face delays due to limited integration of advanced technologies and lack of adequate maintenance culture. The presence of outdated pilot boats and manual scheduling systems has constrained the efficiency and responsiveness of pilotage services. As noted by Ezenwa and Nwosu (2023), these operational deficiencies contribute to longer vessel waiting times, increased port congestion, and reduced service reliability.

### III. METHODOLOGY

The study adopted a descriptive research design using a well-structured questionnaire as the main instrument for data collection. The total population comprised 30 port personnel directly involved in pilotage operations at Onne Port, including 12 Marine Pilots, 10 Vessel Traffic Management and Information System (VTMIS) Officers, and 8 ICT/Technical Staff. These groups were purposively selected for their direct roles in navigation guidance, vessel monitoring, and technological system deployment. A sample size of 28 respondents was obtained using snowballing and incidental sampling techniques. Snowballing was applied to access Marine Pilots and VTMIS Officers with restricted availability, while incidental sampling captured accessible ICT/Technical Staff. Data was analyzed using inferential statistics, with multiple regression analysis.

### IV. RESULT AND DISCUSSION

The results of multiple regression analysis presented in Tables 1 and 2 provide empirical insights into the

role of technological innovation adoption in enhancing pilotage operations at Onne Port, Nigeria. The Model Summary in Table 1 reveals a Multiple R value of 0.891, indicating a strong positive correlation between technological innovation adoption and pilotage operations. The R Square ( $R^2$ ) value of 0.794 suggests that approximately 79.4% of the total variation in pilotage operations is explained by the combined effect of the five technological innovation predictors: Automation of Pilotage Scheduling (APS), Vessel Traffic Management and Information System (VTMIS), Electronic Ship Clearance Systems (ESCS), Port Community System (PCS), and ICT and Maintenance Support System Efficiency (IMSS). The Adjusted  $R^2$  value of 0.748 further confirms the robustness of the model after adjusting for the number of predictors, indicating that the model has a high explanatory power. The Standard Error of 0.309 shows a relatively low level of prediction error, suggesting a good model fit. The ANOVA results further validate the model's statistical significance, with an F-statistic of 16.986 and a corresponding p-value (Sig.) of 0.000, which is well below the 0.05 threshold. This implies that the model as a whole is statistically significant, confirming that technological innovation adoption has a significant joint impact on the effectiveness of pilotage operations at Onne Port.

Table 2 presents the Coefficients of the regression model, providing detailed information about the individual contributions of each technological innovation variable. The Automation of Pilotage Scheduling ( $\beta = 0.249$ ,  $p = 0.041$ ) has a positive and statistically significant effect on pilotage operations, indicating that efficient automation systems contribute to improved scheduling accuracy and timeliness of vessel movements. The Vessel Traffic Management and Information System ( $\beta = 0.503$ ,  $p = 0.000$ ) emerged as the strongest predictor, signifying that enhanced vessel tracking and navigational coordination significantly improve operational safety and efficiency. Similarly, the Electronic Ship Clearance Systems ( $\beta = 0.474$ ,  $p = 0.000$ ) positively influence pilotage performance by facilitating faster documentation, reducing delays, and promoting transparency. The Port Community System ( $\beta = 0.346$ ,  $p = 0.004$ ) also has a significant positive impact, reflecting the importance of integrated information sharing among port stakeholders in streamlining pilotage-related processes. Lastly, the ICT and Maintenance Support System Efficiency ( $\beta$

= 0.433, p = 0.001) shows a strong positive and significant effect, demonstrating that effective ICT infrastructure and maintenance support enhance real-

time operational responsiveness and reduce system downtime.

Table 1: Model Summary and ANOVA<sup>a</sup>

Analysis of Variance Table						
Model		Sum of Squares	Df	Mean Square	F	Sig.
	Multiple R			.891 <sup>a</sup>		
	R Square (R <sup>2</sup> )			.794		
	Adjusted R Square (R <sup>2</sup> )			.748		
	Standard Error			.309		
1	Regression	8.091	5	1.618	16.986	.000 <sup>b</sup>
	Residual	2.096	22	.095		
	Total	10.187	27			

Source: Researcher's Computation (2025)

Table 2: Coefficients<sup>a</sup>

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error			
	(Constant)	-.450	.286		-1.573	.130
	Automation of Pilotage Scheduling	.150	.069	.249	2.172	.041
	Vessel Traffic Management and Information System	.279	.063	.503	4.414	.000
1	Electronic Ship Clearance Systems	.249	.060	.474	4.144	.000
	Port Community System	.211	.066	.346	3.210	.004
	ICT and Maintenance Support System Efficiency	.261	.064	.433	4.045	.001

a. Dependent Variable: Pilotage Operations

Source: Researcher's Computation (2025)

The study reveals that technological innovation adoption significantly enhances pilotage operations at Onne Port, Nigeria. The model's R<sup>2</sup> value of 0.794 indicates that 79% of the variation in pilotage performance is explained by technological factors, confirming a strong predictive relationship. This supports Zhang et al. (2023), who stated that digital innovation improves operational efficiency and maritime safety. The Vessel Traffic Management and Information System (VTMIS) had the strongest influence ( $\beta = 0.503, p < 0.01$ ), aligning with Ibrahim and Yusuf (2022) that real-time vessel monitoring enhances navigation accuracy. The Electronic Ship Clearance System ( $\beta = 0.474, p < 0.01$ ) also showed a strong effect, consistent with Chen and Li (2021) that digital clearance reduces delays and promotes transparency.

The Automation of Pilotage Scheduling ( $\beta = 0.249, p < 0.05$ ) improves time management and operational coordination, supporting Olowu and Mensah (2022). Similarly, the Port Community System ( $\beta = 0.346, p < 0.01$ ) enhances stakeholder communication, as highlighted by Browne and Smith (2023). The ICT and Maintenance Support System Efficiency ( $\beta = 0.433, p < 0.01$ ) confirms Adegboye et al. (2024) that ICT infrastructure strengthens system reliability and reduces downtime. These results affirm that adopting technologies such as VTMIS, automation, electronic clearance, and ICT systems substantially improves accuracy, safety, and efficiency in pilotage operations, positioning Onne Port for greater maritime competitiveness.

## V. CONCLUSION AND RECOMMENDATION

The study concludes that technological innovation adoption significantly enhances pilotage operations at Onne Port, Nigeria, improving efficiency, accuracy, and navigational safety. Innovations such as VTMS, Electronic Ship Clearance, and ICT systems were found to be major contributors to operational effectiveness. It is recommended that the Nigerian Ports Authority invest continuously in modern technologies and capacity-building for port personnel. Strengthening digital infrastructure and fostering stakeholder collaboration will further promote safe, efficient, and competitive maritime operations.

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