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The Influence of Smart Technologies Adoption in Enhancing the Port Efficiency: A Case of Dar Es Salaam Seaport, Tanzania

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Abstract *— Smart technologies have revolutionized port operations making the port activities and processes more efficient. This study examined the influence of smart technology adoption on enhancing operational efficiency at the Dar es Salaam seaport, Tanzania's largest and busiest port. The research was guided by three specific objectives corresponding with smart technology selected components including system automation, real-time data integration, and cybersecurity on port efficiency. The study adopted positivism philosophy and deductive research approach with a descriptive design employed in entire process of methodology. The study collected data from a sample of 95 respondents drawn randomly from port management, shipping companies, and shipping agents. Data collection instruments included structured questionnaires and documentary reviews. Analysis was carried out through descriptive statistics and multiple regressions by using SPSS software. The results of descriptive statistics show that the aggregate average mean of all three variables lie in "agree level" of the liker scale indication that respondents agreed that adoption of smart technology through system automation, real-time data integration, and cybersecurity contributed to port efficiency. Findings of the study demonstrated that system automation had significant enhancement to port efficiency, with a strong positive correlation, indicating that increased automation leads to better operational outcomes. Real-time data integration showed a positive but statistically weaker impact on port efficiency, suggesting benefits that are present but less pronounced. Cybersecurity also demonstrated a significant positive effect on port efficiency, suggesting that increased usage of cybersecurity technology leads to better improved operational outcomes. The study concludes that smart technologies, especially automation and cybersecurity, play critical roles in improving the efficiency of Dar es Salaam seaport operations. The study recommends the port management to continue investing in these smart technologies in parallel with efforts to strengthen real-time data systems for optimal port efficiency. These findings may contribute valuable insights to the port authorities and the government focusing to leverage technology to enhance port operational efficiency.*

Keywords — ***Smart Technologies, Port Efficiency, Automation, Real-Time Data Integration, Cybersecurity, Dar es Salaam Seaport***

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I. INTRODUCTION

Ports are the backbone of international trade and crucial nodes in global supply chains. Over the last decade, the maritime sector has experienced rapid technological change, driven by the emergence of Industry 4.0 technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), blockchain, and advanced automation. These innovations promise significant improvements in operational efficiency, safety, environmental performance, and stakeholder coordination. In many global ports particularly those in advanced economies smart solutions have reduced vessel turnaround times, improved cargo throughput, and enhance resources utilization

Dar es Salaam seaport is Tanzania's largest and busiest port, handling the majority of the country's international maritime traffic. The port plays a critical role not only in Tanzania's economy but also as a gateway for several landlocked neigh boring countries. Historically, Dar es Salaam has experienced challenges common to many growing ports in lower-middle-income countries: terminal congestion, long vessel waiting times, manual and paper-based workflows, inconsistent data flows, and periodic security vulnerabilities. In response, the Tanzania Ports Authority (TPA) and related stakeholders have begun to adopt smart technologies such as Port Community Systems (PCS), Automated Cargo Handling Systems, IoT enabled sensors, Electronic Data Interchange (EDI), and targeted cybersecurity measures to modernize operations and improve performance (TPA, 2023; TASAC, 2024). These interventions mirror global smart port trends but also face context-specific barriers, including limited interoperability across legacy systems, skills shortages, high capital costs, and infrastructure constraints.

This study evaluates how adoption of three core dimensions of smart technology system automation, real-time data integration, and cybersecurity affects operational efficiency at Dar es Salaam. Operational efficiency is conceptualized here as the port's ability to optimize resources, reduce turnaround and dwell times, minimize operational costs, and maintain service quality. The research addresses a local empirical gap: while the academic literature has produced many studies on smart ports in advanced settings, empirical evidence from Tanzanian and comparable African ports remains limited. By focusing on Dar es Salaam and using primary data collected from port personnel and stakeholders, this paper contributes context-sensitive evidence for policy and practice.

Literature Review

This literature review synthesizes theoretical perspectives and empirical studies on smart ports and the roles of automation, real-time data integration, and cybersecurity in port efficiency.

Theoretical Framework: Theory of Technology Dominance (TTD) Theoretical.
The Theory of Technology Dominance (TTD) suggests that increased adoption of technology shifts decision-making and execution toward data-driven, automated systems, thereby reducing human error and improving consistency and speed. In port contexts, TTD implies that advanced digital tools can decentralize information flows, improve situational awareness, and enable proactive operational control. TTD provides the conceptual basis for expecting positive effects of automation, real-time integration, and cybersecurity on operational outcomes.

Empirical Evidence
Automation: Studies from a range of ports indicate that automated handling systems, automated stacking cranes, and yard-management software lead to reduced manual errors, higher productivity, and lower Labor costs (Yau et al., 2020; Rodrigo González et al., 2020). Automation is often cited as the most direct path to measurable improvements in throughput and vessel turnround times.

Real-time Data Integration: Real-time systems driven by IoT sensors, AIS data, and integrated information platforms support faster, better-informed decisions and improved coordination among stakeholders. Research suggests that real-time data improves berth allocation, yard utilization, and multimodal coordination, though benefits depend heavily on interoperability data quality (Yang & Hsieh,2024; Wang et al.,2022)

Cybersecurity: As ports digitize, cybersecurity becomes critical for ensuring continuity and trust. Cyber incidents can paralyze operations, causing lengthy delays and economic losses. Studies emphasize the need for layered security, access controls, and staff training to protect port operations (Karli et,.2021; Karas,2022)

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Vol. 6 No. 5 – October 2025

Gaps: Much of the literature focuses on developed ports; studies addressing African ports are fewer and often descriptive. There is a need for empirical, locally grounded analyses that quantify the effects of specific dimensions of smart technologies on operational metrics in African contexts such as Dar es Salaam.

Conceptual Framework

The conceptual framework of this study proposes a system Automation, Real time data integration and Cyber security as independent variables with a Operation efficiency as a dependent variable

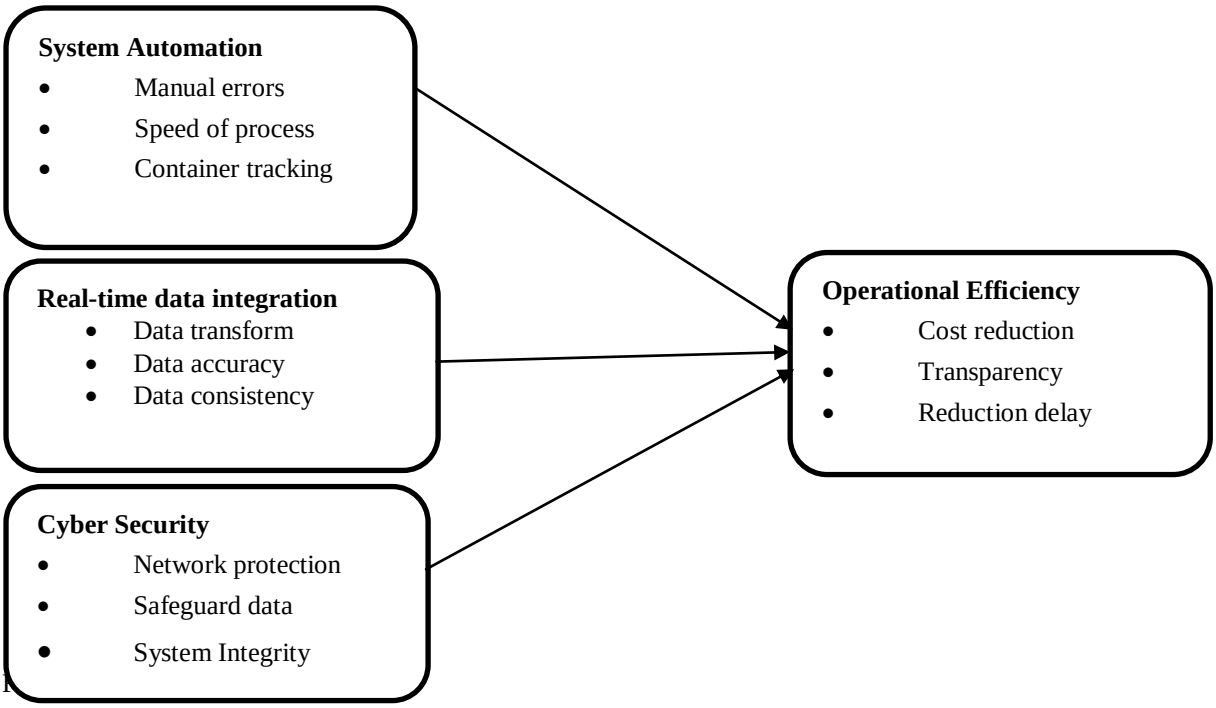

Figure 1: Conceptual framework

Source: Adopted from Karaś (2022)

II.METHOD

Research Design and Approach

The study follows a positivist philosophy and employs a quantitative descriptive research design.

The approach is deductive: hypotheses about positive relationships between smart technology dimensions and port efficiency are tested using survey data and statistical modelling.

Population and Sampling.

The target population included employees and staff from Tanzania Ports Authority (TPA), shipping companies operating at the port (e.g., MSC, Maersk, PIL, Hapag-Lloyd, Evergreen, COSCO), and shipping agents and freight forwarders. The estimated population in 2024 was approximately 3,645 employees across these groups. Using Yamane's formula with a 10% margin of error, the calculated sample size was approximately 97 respondents. Stratified sampling was used to ensure representation across the three main strata (TPA management, shipping companies, and shipping agents), with simple random sampling within each stratum.

Data Collection and Instrumentation

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Vol. 6 No. 5 – October 2025

Primary data were collected through structured questionnaires. The questionnaire included demographic items and Likert-scale questions (1-5) measuring perceptions of automation, real-time integration, cybersecurity, and operational efficiency. Secondary data included port reports, government publications, and peer-reviewed literature to contextualize findings.

Data Analysis.

Data were analysed using descriptive statistics (means, standard deviations, frequencies), reliability analysis (Cronbach's alpha), Pearson correlation coefficients, and multiple linear regression to quantify the effects of the predictors on operational efficiency. Statistical analysis was performed using SPSS v.30.

Validity, Reliability and Ethical Considerations.

Validity was addressed through instrument pre-testing and supervisory review; reliability was assessed via Cronbach's alpha (threshold 0.7). Ethical procedures included institutional clearance, informed consent, and confidentiality assurances.

III. RESULT AND DISCUSSION

A. Results

This section presents descriptive and inferential findings from the survey and document review. Key subsections include response rate, reliability analysis, respondent demographics, descriptive results for each construct, correlations, and regression results.

Response Rate and Reliability

A total of 97 questionnaires were distributed, of which 94 were returned fully completed, yielding a response rate of 96.1% well above commonly accepted thresholds for survey research in organizational settings. Reliability analysis using Cronbach's alpha produced the following coefficients: Automation ($\alpha = 0.830$), Real-time integration ($\alpha = 0.849$), Cybersecurity ($\alpha = 0.791$), and Operational Efficiency ($\alpha = 0.701$). All scales exceeded the conventional 0.70 threshold, indicating satisfactory internal consistency.

Respondent Demographics

Table 1: Demographic summary (selected items)

Characteristic	Category	Percent (%)
Age	25-40 years	43.2
Age	41-50 years	35.8
Education	Undergraduate degree	51.6
Education	Master's degree	32.6
Experience	6-10 years	43.2
Experience	11-15 years	22.1

Descriptive Statistics for Constructs

Mean scores on the 5-point Likert scale indicate general agreement that smart technologies positively influence port efficiency. Aggregate means were: Automation = 4.43; Real-time integration = 4.51; Cybersecurity = 4.28; and Overall Smart Technologies influence = 4.48.

Correlation Analysis

Pearson correlation coefficients show statistically significant positive associations between each predictor and operational efficiency. Key correlations include: Automation Operational Efficiency $r = 0.565$ ($p < 0.01$); Real-time Integration Operational Efficiency $r = 0.494$ ($p < 0.01$); Cybersecurity Operational Efficiency $r = 0.488$ ($p < 0.01$).

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Multiple Regression Results
Table 2: Regression coefficients predicting Operational Efficiency

Predictor	B (Unstd)	Std. Error	Beta	p-value
Automation	0.213	0.063	0.345	0.001
Real-time Integration	0.138	0.070	0.198	0.052
Cybersecurity	0.155	0.065	0.229	0.019

Model summary: R = 0.636; R^2 = 0.405; Adjusted R^2 = 0.385; Std. Error = 0.42141. These results indicate that the three predictors jointly explain about 40.5% of variance in operational efficiency.

B. Discussion

The study's findings highlight automation as the most influential smart technology dimension for improving port efficiency at Dar es Salaam. Automation's strong association with efficiency is consistent with international literature that points to automation as a primary driver of throughput gains and error reduction (Yau et al., 2020). At Dar es Salaam, automation appears to have enhanced consistency, sped up processing, reduced labor costs, and contributed to better yard management.

Cybersecurity emerged as a statistically significant predictor, underscoring that digital adoption must be accompanied by robust security measures. Cyber threats can cause severe disruptions; hence cybersecurity investments protect both data integrity and continuity of operations (Karli et.,2021)

Real-time data integration showed positive but marginally insignificant effects in the regression model. This suggests that while stakeholders recognize the value of real-time data, full benefits depend on system interoperability, data quality, and stakeholder adoption. For real-time integration to deliver measurable gains, port systems must ensure seamless exchange of standardized, high-quality data across multiple sectors.

The model's R^2 (0.405) indicates that while smart technologies are important, other factors such as regulatory procedures, hinterland transport linkages, labor practices, and infrastructure capacity also influence port efficiency. Therefore, technology investments should be part of a holistic strategy that includes process reengineering, stakeholder collaboration, and capacity building.

IV. CONCLUSION

This study examined how smart technologies automation, real-time data integration, and cybersecurity have influenced operational efficiency at the Port of Dar es Salaam. Guided by the Theory of Technology Dominance, which stresses reducing human reliance and enhancing system accuracy, the study found that automation had the strongest positive effect. Automated systems in cargo handling, container tracking, and inventory control reduced errors, accelerated operations, minimized vessel waiting times, and improved utilization of space and resources. These efficiencies enhanced service delivery and lowered operational costs.

Real-time data integration, though with a weaker influence, proved valuable in improving coordination, decision-making, and information sharing among stakeholders such as shipping companies, customs, and freight forwarders. It facilitated cargo tracking, resource scheduling, and rapid responses to disruptions, thereby reducing delays and strengthening planning.

Cybersecurity was also critical for sustaining efficiency as digitalization increased exposure to risks such as hacking and data theft. Robust security systems were essential for protecting sensitive information, ensuring system integrity, and maintaining stakeholder trust. Overall, the adoption of smart technologies has significantly supported the Port of Dar es Salaam in achieving more secure, efficient, and cost-effective operations.

Recommendation for Future Research and Limitations of the study.

C. Recommendation

This study examined the influence of smart technology adoption on enhancing operational efficiency at the Port of Dar es Salaam. Findings related to the key components of a smart port—automation, real-time data integration, and cybersecurity revealed notable improvements in efficiency and highlighted areas requiring further development. Based on these findings, several recommendations are proposed to strengthen digital transformation and sustain operational performance.

First, as advanced systems are introduced, the port should invest continuously in capacity building and technical training. Equipping employees with relevant skills in automation and digital system management will ensure effective technology utilization and optimize operational performance.

Second, to enhance coordination and communication among departments, the port should establish a unified digital platform integrating logistics, customs, and inventory management systems. Such integration will facilitate seamless real-time data exchange, supporting faster and more accurate decision-making across all operational units and stakeholders.

Third, as digitalization advances, maintaining robust cybersecurity measures is critical. The Port Authority should implement regular security audits, system updates, and vulnerability testing to prevent data breaches and ensure compliance with international cybersecurity standards.

Finally, the port should develop a long-term strategic roadmap aligning technological innovation with broader economic and operational goals. This plan will provide a clear framework for guiding investments, policy formulation, and partnerships to sustain digital transformation and promote continuous efficiency gains.

D. Limitations of the Study

Despite providing valuable insights into the impact of smart technology adoption on operational efficiency at the Port of Dar es Salaam, this study faced several limitations that may affect the scope and generalizability of its findings.

Scope Limitation: The study focused on three key components—automation, real-time data integration, and cybersecurity. Although critical, other emerging technologies such as artificial intelligence, blockchain, and the Internet of Things (IoT) were not examined, limiting the study's comprehensiveness. The researcher defined the study boundaries, justified the selected focus areas as most relevant for immediate operational gains, and recommended future studies to include additional technologies for broader assessment.

Data Access Constraints: Access to detailed operational data and proprietary records was restricted due to confidentiality and security policies. As a result, the analysis relied partly on secondary sources and staff perceptions gathered through questionnaires and interviews. This may have limited the depth of analysis on metrics such as cargo handling time or system downtime. To mitigate this, the researcher triangulated multiple data sources to ensure reliability and a more complete understanding despite restricted access.

Respondent Bias: Since data were collected from port staff and management, responses may reflect social desirability or underreporting of challenges, influencing findings on technology adoption and operational efficiency. To minimize bias, anonymity was assured, mixed methods were applied, and responses were cross-verified across respondent groups to enhance credibility.

Time Constraints: The study was conducted within a limited timeframe, restricting the observation of long-term trends or seasonal variations in port operations. Thus, findings represent a short-term snapshot rather than a longitudinal perspective. The researcher focused on measurable short-term efficiency indicators and recommended future longitudinal studies to capture long-term technological impacts.

Areas for Future Research

The study demonstrates the potential of smart technologies to enhance operational efficiency at the Port of Dar es Salaam. However, further research is needed to deepen understanding and inform policy and management strategies.

AI Applications and Financial Performance: Future research should examine how artificial intelligence (AI) can be applied in port operations to enhance both operational and financial performance using measurable metrics. Prior studies show AI enabling automation in container handling, optimizing ship traffic management, and improving operational accuracy in ports, which all positively impact efficiency

Social and Economic Impacts of Automation: Research is needed to investigate how automation affects labor markets, including workforce displacement, skill gaps, and changes in employment levels. For instance, studies in Chile show that automation creates job displacement but also generates new roles, resulting in mixed net employment effects depending on the context.

Comparative Port Studies: Comparative analyses between Dar es Salaam and other regional ports (e.g., Tanga, Mtwara, or Mombasa) will help assess differences in digital readiness, technology adoption, and productivity outcomes. A recent comparative study between Dar es Salaam and Mombasa using a DEA-CVA model revealed fluctuating efficiency scores and contextual externalities affecting performance.

Long-Term Economic Benefits of Technological Investment: Longitudinal studies are recommended to assess the long-term economic returns of technological investments at the port, especially in dimensions such as revenue growth, customer satisfaction, equipment uptime, and cost savings. Evidence from ports in China and elsewhere indicates that digital transformations can reduce operating costs, improve decision-making speed, and cut delays significantly.

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