

# Assessing the Impact of Automated Cargo-Handling Systems on Operational Efficiency at Dar es Salaam Port, Tanzania

Vitus Charles Mwaya<sup>1</sup> | Lucas P. Mwisila<sup>2</sup>

<sup>1,2</sup> Dar es Salaam Maritime Institute, Dar es Salaam, Tanzania.

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## Abstract:

This study assesses how Automated Cargo-Handling (ACH) systems influence operational efficiency at Dar es Salaam Port, Tanzania's primary maritime gateway. Employing a convergent mixed-methods design, it integrates quantitative data from 96 structured questionnaires (Cronbach's  $\alpha = .842$ ) and port-efficiency metrics with qualitative insights from 20 semi-structured interviews and three days of quay-side observation. Respondents rated ACH benefits highly ( $M = 4.12/5$ ), and Pearson's correlation ( $r = .642, p < .001$ ) confirmed a strong positive relationship between ACH adoption and a composite Port-Efficiency Index. Multiple regression showed ACH contributed uniquely to 27.8 % of efficiency variance ( $\beta = .278, p < .001$ ), even when controlling for complementary technologies, cybersecurity, and workforce competence. Thematic analysis revealed "Operational Acceleration" as a dominant theme, corroborated by a 41 % reduction in average vessel-quay working time (12.6 h to 7.4 h). While mechanization drives significant throughput gains, moderate challenge scores underscore the need for resilient power backing and targeted maintenance training. Findings inform policy and operational strategies, guiding port authorities in balancing hard-automation investments with infrastructure and capacity-building measures to sustain long-term performance gains.

**Keywords:** Automated Cargo-Handling, Port Efficiency, Throughput, Vessel Turnaround

## 1. Introduction:

Containerization has fundamentally transformed maritime logistics by standardizing cargo units and streamlining handling processes, while mechanization has further accelerated port operations through the deployment of advanced machinery. Over the past four decades, ports worldwide have progressively evolved from labor-intensive docks to technology-driven terminals, integrating robotics, automated cranes, and real-

time data systems to enhance throughput (Notteboom & Rodrigue, 2008). These innovations promise to reduce turnaround times, mitigate human error, and optimize resource allocation, thereby elevating ports' competitive positioning within global supply chains.

At the forefront of these advancements are Automated Cargo-Handling (ACH) systems, which typically encompass twin-lift ship-to-shore

cranes, automated guided vehicles (AGVs), and computer-controlled yard-stacking cranes. Twin-lift cranes enable simultaneous handling of two 20-foot containers or one 40-foot container, effectively doubling lift rates per cycle, while AGVs transport containers between quay and yard without human intervention (Lee & Song, 2019). Yard-stacking robots further enhance storage density and retrieval speed by operating on predefined paths under centralized scheduling algorithms. Together, these components form an integrated ACH ecosystem designed to compress load/unload cycles and minimize idle equipment time.

Dar es Salaam Port serves as Tanzania's principal maritime gateway, handling approximately 95% of the nation's seaborne trade and acting as a crucial logistics hub for landlocked neighbours such as Rwanda, Uganda, Zambia, Burundi, and the Democratic Republic of the Congo (TPA, 2023). In recognition of its strategic importance, the Tanzania Ports Authority has embarked on a phased modernization programme encompassing infrastructure upgrades and partial automation of key processes. Despite these investments, anecdotal reports suggest persistent operational bottlenecks, raising questions about the real-world efficacy of ACH technologies under local conditions.

Port operational efficiency is conventionally gauged using metrics such as vessel turnaround time, berth productivity (measured in moves per hour), and container dwell time in the yard (Heilig, Schwarze, & Voß, 2017). Empirical research in major European ports such as Rotterdam and Hamburg has documented throughput gains of up to 30% following full ACH implementation, attributing improvements to reduced crane idle time and more predictable yard operations (Lee & Song, 2019; Meisel, 2016). These studies also highlight the role of predictive maintenance and data-driven scheduling in sustaining high levels of equipment availability.

However, comparable evidence from sub-Saharan Africa remains scant. The World Bank (2021)

notes that Mombasa and Lagos ports have experimented with limited automation, but face significant hurdles, including unreliable power supply, shortages of technical expertise, and fragmented legacy IT systems that undermine end-to-end process integration (Joubert, 2018). Such contextual constraints may attenuate the performance gains observed in more developed settings, thereby necessitating targeted investigation into how ACH systems perform in emerging-market environments.

This study addresses that gap by investigating the impact of Automated Cargo-Handling systems on operational efficiency at Dar es Salaam Port. Employing a convergent mixed-methods design, it integrates quantitative data from structured stakeholder surveys with qualitative insights gleaned from interviews and field observations. By focusing specifically on ACH's contribution to key performance indicators vessel turnaround, berth productivity, and yard dwell time this research constructs a holistic evidence base to inform policy and operational strategies.

## 2. Literature Review:

### 2.1 The Evolution of Container-Handling Technologies

Since the advent of containerization in the 1950s and 1960s, ports have undergone a profound transformation from manual break-bulk operations to mechanized handling of uniform cargo units. Initial automation efforts focused on the introduction of rubber-tyred gantries (RTGs) to streamline yard stacking and retrieval, thereby reducing reliance on labor-intensive straddle carriers and forklifts. Notteboom and Rodrigue (2008) characterize this period as the first technological wave, during which standardization of container sizes enabled the creation of dedicated intermodal terminals and the emergence of specialized handling equipment.

The second wave, beginning in the 1990s, saw the deployment of automated stacking cranes (ASCs) and the gradual integration of automated guided vehicles (AGVs) on terminal aprons. ASCs operate on rail tracks, allowing precise, high-

density storage and retrieval with minimal human intervention, while AGVs transport containers between quay cranes and yard stacks along programmed paths. Lam and Yap (2015) note that real-time scheduling algorithms now coordinate these assets to optimize throughput, reduce bottlenecks, and minimize idle equipment time. Together, these technologies form the backbone of modern automated cargo-handling ecosystems, enabling ports to scale operations with greater reliability and safety.

## 2.2 ACH Systems and Throughput Gains

Empirical evidence from Northern European ports underscores the substantial productivity improvements achievable through twin-lift ASCs and integrated AGV operations. In the Port of Rotterdam, Lee and Song (2019) report that the introduction of twin-lift cranes capable of handling two 20-foot containers or one 40-foot container per cycle yielded quay productivity increases of 20–30 %. These gains derive primarily from reduced crane idle time and smoother hand-offs between quay and yard operations. Similarly, Meisel (2016) found that in Hamburg, average crane cycle time decreased from 3.2 minutes to 2.1 minutes following full ASC deployment, translating into a 15 % rise in vessel service capacity.

Beyond lift rates, predictive maintenance regimes and terminal-management software integration have amplified the impact of ACH systems. Automated condition monitoring sensors on cranes and AGVs enable real-time fault detection, minimizing unplanned downtime and extending equipment lifespan. Integrated terminal-management systems synchronize quay operations with yard stacking and gate processing, ensuring optimal resource allocation and reducing vessel dwell times (Notteboom & Rodrigue, 2008). This synergistic approach combining physical automation with digital orchestration has become a hallmark of high-efficiency terminals.

## 2.3 Challenges in Emerging-Market Ports

Despite clear benefits in developed contexts, the adoption of full ACH systems in emerging-market

ports faces distinctive obstacles. The World Bank (2021) highlights that at Mombasa Port, frequent power outages interrupt ASC operations, forcing terminals to revert to rubber-tyred gantries during blackout events. High upfront capital costs and extended payback periods further deter full automation investment, particularly where financing options are limited and cargo volumes fluctuate seasonally. Such infrastructural vulnerabilities can erode anticipated throughput gains and undermine stakeholder confidence.

Moreover, Joubert (2018) identifies a “confidence gap” among local operators stemming from insufficient training in robotics maintenance and diagnostics. When ASCs or AGVs malfunction, terminal staff often lack the expertise to perform swift repairs, leading to prolonged downtime and reliance on external vendor support. Institutional fragmentation compounds these issues: port authorities, customs agencies, and shipping lines frequently operate disparate IT systems with limited interoperability, undermining end-to-end process automation and perpetuating manual workarounds (Schiller et al., 2019). These systemic constraints necessitate complementary investments in human capital and governance frameworks.

## 2.4 Theoretical Framework: Port Competitiveness Theory

Port Competitiveness Theory posits that mechanization and digitalization are primary determinants of throughput efficiency and modal attractiveness (Yuen & Wang, 2013). Under this framework, ports compete on the basis of cost, time, and reliability, leveraging automation to reduce unit handling costs and vessel turnaround times. By achieving higher productivity levels, ports can attract additional shipping services and cargo flows, creating positive network effects that reinforce their competitive positions within global supply chains.

A central tenet of the theory is the “virtuous cycle” wherein efficiency gains generate surplus capacity and resources that can be reinvested in further technological upgrades and infrastructure

enhancements (Notteboom & Rodrigue, 2008). Operational resilience underpinned by robust power supplies, predictive maintenance, and a skilled workforce emerges as a critical mediator of this cycle. Without resilient supporting systems, automation investments may fail to deliver sustained performance improvements, highlighting the importance of a holistic approach that integrates technology with organizational and regulatory alignment.

## 2.5 Summary and Research Gap

The review of container-handling evolution and ACH performance in developed ports demonstrates the transformative potential of mechanized systems, with documented quay productivity gains of up to 30 % and significant reductions in vessel dwell times (Lee & Song, 2019; Meisel, 2016). However, emerging-market contexts such as East Africa present unique challenges power reliability, high capital costs, limited technical expertise, and institutional fragmentation that can attenuate these benefits (World Bank, 2021; Joubert, 2018; Schiller et al., 2019). While theoretical frameworks like Port Competitiveness Theory offer a lens for understanding the mechanisms of automation-driven efficiency, empirical assessments in sub-Saharan Africa remain scarce.

Dar es Salaam Port's ongoing partial automation provides a valuable case for evaluating how contextual factors shape ACH impacts. Specific Objective 1 of this study assessing the influence of Automated Cargo-Handling systems on operational efficiency addresses this gap by combining quantitative port-performance metrics with qualitative stakeholder insights. In doing so, the research will elucidate not only the magnitude of throughput gains but also the conditions under which ACH systems can be sustainably leveraged in emerging-market ports.

## 3. Methodology:

### 3.1 Research Design

A convergent mixed-methods design was implemented to triangulate quantitative

performance metrics with qualitative experiential insights, ensuring a comprehensive assessment of ACH impacts. The quantitative strand comprised 96 structured questionnaires that captured stakeholder perceptions of ACH efficiency gains and implementation challenges on a five-point Likert scale. Concurrently, empirical port-efficiency metrics including throughput per hour, average vessel dwell time, and crane utilization rates were extracted from the Tanzania Ports Authority's Management Information System (TPA MIS).

The qualitative strand involved 20 semi-structured interviews with key informants TPA operations managers, IT specialists, and ship-to-shore crane operators and three full days of non-participant observation at the quay. Interview protocols probed participants' lived experiences with ASC and AGV functionality, maintenance routines, and breakdown responses, while observational checklists documented real-time cycle times, hand-off sequences, and equipment overrides. By integrating these parallel datasets, the design enabled corroboration of statistical trends with stakeholder narratives, bolstering the study's internal validity.

### 3.2 Sampling and Data Collection

Purposive sampling targeted individuals who possessed direct operational or managerial responsibility for ACH systems at Dar es Salaam Port. Senior TPA officials overseeing terminal automation, customs representatives stationed at the gate complex, RTG/ASC operators, and maintenance engineers formed the core interview cohort. This approach ensured that participants had the necessary domain expertise to speak authoritatively on both system performance and contextual constraints.

For the questionnaire survey, a stratified sample frame was constructed to reflect the port's functional composition: 48 TPA officials, 10 customs officers, 10 logistics-service providers, 9 IT specialists, and 19 importers/exporters. Invitations were distributed via email and in-person briefing sessions, achieving a 87.3 %

response rate (n = 96). Interviews were scheduled to accommodate shift patterns and operational demands, with on-site observation sessions conducted across peak (07:00–15:00) and off-peak (15:00–23:00) windows to capture variability in ACH performance.

### 3.3 Instrument Reliability and Validity

The internal consistency of the ACH perception scale (k = 5 items) was assessed using Cronbach’s alpha, yielding  $\alpha = .842$  and exceeding the .70 benchmark for reliability. Pilot testing with a subset of 12 port staff revealed no ambiguous items, and minor wording adjustments improved clarity. This rigorous pre-testing phase strengthened the dependability of subsequent survey responses.

Validity was addressed on three fronts. Content validity was established through expert review: port-automation engineers and terminal-management consultants evaluated the instrument for coverage and relevance. Construct validity aligned each survey item with theoretical definitions from Notteboom and Rodrigue (2008), ensuring that “ACH efficiency” and “implementation challenges” captured distinct conceptual domains. External validity was supported by benchmarking the mean ACH score (M = 4.12) against published European port data (Meisel, 2016), confirming that the scale operated comparably across contexts.

### 3.4 Data Analysis

Quantitative data were processed in SPSS v28. Descriptive statistics (means, standard deviations) summarized stakeholder perceptions of ACH benefits and challenges. Pearson’s correlation coefficient tested the bivariate relationship between ACH scores and a composite Port-Efficiency Index (throughput/hour, vessel dwell time), while a standard-enter multiple-regression model isolated ACH’s unique effect ( $\beta_1$ ) on efficiency, controlling for other automation constructs. Variance inflation factors (VIF) confirmed negligible multicollinearity (< 1.6), and the model’s  $R^2$  of .58 indicated substantive explanatory power.

Qualitative transcripts were managed in NVivo 12 and subjected to thematic analysis following Braun and Clarke’s (2013) six-phase framework. Initial open coding generated categories related to “Operational Acceleration,” “Breakdown Responses,” and “Power-Supply Interruptions.” Axial coding then linked these categories to broader themes of system reliability and human-machine interaction. Finally, pattern mapping compared emergent themes against quantitative findings, enabling integrative interpretation of how ACH technologies translated into measurable throughput gains at Dar es Salaam Port.

## 4. Results and Findings:

### 4.1 Descriptive Insights

Respondents rated ACH efficiency gains at a mean of 4.12 (SD = 0.78), indicating “High” agreement that mechanized cranes improved throughput. Implementation challenges averaged 3.47 (SD = 0.93), reflecting moderate concerns over power reliability and maintenance lead-times. Table 1 summarizes these statistics.

**Table 1 Descriptive Statistics for ACH Constructs**

Item	Mean	SD	Interpretation
ACH increases quay productivity	4.25	0.64	Very High
Dual-lift capability reduces cycle time	4.08	0.71	High
AGVs minimize yard hand-offs	4.01	0.89	High
Power-outage downtime disrupts operations	3.36	1.02	Moderate Challenge
Maintenance lead-time delays crane readiness	3.50	0.87	Moderate Challenge

Source: Field Data (2025)

Table 4.1 presents respondents’ aggregated perceptions of five key aspects of Automated Cargo-Handling (ACH) at Dar es Salaam Port, expressed as means and standard deviations on a 1–5 Likert scale alongside interpretive labels. The top three items “ACH increases quay productivity” (M = 4.25, SD = 0.64), “Dual-lift capability reduces cycle time” (M = 4.08, SD = 0.71), and “AGVs minimize yard hand-offs” (M = 4.01, SD = 0.89) all fall into the “High” or “Very High” agreement bands. These elevated means, coupled with relatively low standard deviations, indicate strong and consistent consensus among stakeholders that mechanized cranes and automated guided vehicles substantially accelerate container loading/unloading operations and streamline intermodal transfers.

In contrast, the final two items highlight moderate implementation challenges: “Power-outage downtime disrupts operations” registers a mean of 3.36 (SD = 1.02), and “Maintenance lead-time delays crane readiness” scores 3.50 (SD = 0.87). These moderate means reflect widespread recognition of infrastructural and logistical constraints namely, grid instability and technical support lags that temper the full potential of ACH systems. The larger standard deviations on these items suggest more varied experiences across respondents, signifying that while some operators seldom encounter outages or delays, others face frequent disruptions that undermine overall system reliability.

#### 4.2 Correlation Analysis

**Table 2. Pearson Correlation between ACH and Port-Efficiency Index (PEI)**

	ACH Score	PEI
ACH Score	1.000	

<b>Port-Efficiency Index</b>	0.642	1.000
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**Source:** Field Data (2025)

Table 2 displays the Pearson product–moment correlation coefficient ( $r = .642$ ,  $p < .001$ ) quantifying the linear relationship between stakeholders’ perceptions of Automated Cargo-Handling (ACH) effectiveness and the composite Port-Efficiency Index (PEI). An r-value of .642 signifies a strong positive association, indicating that higher ACH scores reflecting beliefs in crane productivity gains, dual-lift efficiency, and AGV performance coincide with superior port performance metrics such as throughput per hour, reduced vessel dwell times, and more effective berth utilization. The significance level (two-tailed  $p < .01$ ) confirms that this correlation is highly unlikely to be due to random chance, underscoring the empirical linkage between mechanized cargo-handling and operational outcomes at Dar es Salaam Port.

From a practical perspective, the shared variance ( $r^2 \approx .412$ ) suggests that roughly 41 % of the variability in port-efficiency measures can be explained by differences in ACH adoption perceptions alone. This substantial overlap corroborates the central premise of Port Competitiveness Theory, which posits mechanization as a core driver of terminal productivity (Yuen & Wang, 2013). Nevertheless, the remaining 59 % of unexplained variance highlights that other factors such as digital documentation processes, terminal-management systems, workforce competence, and cybersecurity readiness also play meaningful roles in shaping overall efficiency, justifying the inclusion of these constructs in the subsequent regression analysis.

#### 4.3 Multiple Regression Results

**Table 3. Standard Multiple-Regression Predicting Port-Efficiency Index (PEI)**

Predictor	$\beta$	SE	t	p	VIF
(Constant)	0.421	0.318	1.32	.190	—
Automated Cargo-Handling	0.278	0.071	3.93	.000	1.44

Digital Documentation	0.193	0.064	3.01	.003	1.38
Terminal-Management Systems	0.311	0.068	4.57	.000	1.52
Cybersecurity Readiness	0.112	0.054	2.07	.041	1.17
Workforce Competence	0.096	0.047	2.02	.046	1.13

Source: Field Data (2025)

Table 3 presents the results of a standard multiple-regression analysis in which the Port-Efficiency Index (PEI) is regressed simultaneously on five predictors: Automated Cargo-Handling (ACH), Digital Documentation Processes (DDP), Terminal-Management Systems (TMS), Cybersecurity Readiness (CSR) and Workforce Competence (WFC). The overall model explains 58 % of the variance in PEI ( $R^2 = .58$ ,  $F(5, 90) = 25.06$ ,  $p < .001$ ), indicating a strong collective effect of these variables on port performance. The Durbin-Watson statistic of 1.89 lies close to the ideal value of 2, suggesting that autocorrelation of residuals is not a concern.

Examining individual coefficients, ACH emerges as a significant positive predictor ( $\beta = .278$ ,  $t = 3.93$ ,  $p < .001$ ), signifying that every one-unit increase in perceived ACH effectiveness is associated with a .278-unit rise in the Port-Efficiency Index, holding other factors constant. TMS shows the largest unique effect ( $\beta = .311$ ,  $t = 4.57$ ,  $p < .001$ ), followed by DDP ( $\beta = .193$ ,  $t = 3.01$ ,  $p = .003$ ). Although smaller in magnitude, CSR ( $\beta = .112$ ,  $p = .041$ ) and WFC ( $\beta = .096$ ,  $p = .046$ ) also contribute significantly, underlining the importance of cybersecurity and human-capital readiness as enabling conditions for sustaining automation gains. Variance Inflation Factors (all  $< 1.6$ ) confirm that multicollinearity among predictors is negligible.

From an operational standpoint, these findings highlight that while hard-automation investments particularly in terminal-management algorithms and automated cranes drive the bulk of efficiency improvements, complementary investments in digital documentation, cyber-governance, and workforce upskilling are necessary to fully realize and protect those gains. The model suggests that a balanced strategy, which pairs further

mechanization with robust cybersecurity measures and targeted training programs, will yield the most resilient and enduring improvements in port operational efficiency.

#### 4.4 Qualitative Theme: Operational Acceleration

Stakeholders consistently described a palpable surge in cargo-handling pace following the deployment of twin-lift ship-to-shore cranes and automated guided vehicles. As one senior operations manager observed, “Since the twin-lift cranes went live we clear a 2,000 TEU vessel three hours faster than last season” (TPA-04), encapsulating the widespread sentiment that mechanized lift capability has reshaped daily workflows. Interviewees credited real-time scheduling algorithms for coordinating crane assignments and AGV dispatches, thereby eliminating idle crane movements and synchronizing yard transfers to maintain continuous throughput. This orchestration of quay-side automation was described as “a seamless dance of steel and software,” reflecting users’ enthusiasm for the way integrated control systems pre-emptively adjust to vessel arrival patterns and yard-stack demands.

Field-observation logs substantiated these perceptions with hard metrics: average vessel-quay working times plummeted from 12.6 hours pre-automation to 7.4 hours post-implementation, a 41 % reduction that directly corresponded to the reported three-hour time savings per 2,000 TEU call. Operators noted, however, that this acceleration was not wholly immune to infrastructure fragilities: during unplanned power dips, port staff frequently initiated manual overrides to reposition cranes or reroute AGVs, momentarily reverting to legacy procedures until

grid stability was restored. These fallback episodes though rare revealed lingering confidence gaps in fully trusting automated sequences, underscoring the need for robust power-backup solutions and further strengthening of operator training to sustain the gains of operational acceleration.

## 5. Discussion:

### 5.1 Throughput Gains and Global Benchmarks

The mean ACH score of 4.12 and a Pearson correlation of  $r = .642$  between ACH perceptions and measured port efficiency confirm that mechanised cargo-handling has delivered substantial productivity improvements at Dar es Salaam Port. These findings mirror those from leading European terminals: Lee and Song (2019) documented 20–30 % throughput uplifts following twin-lift ASC deployment in Rotterdam, while Meisel (2016) reported a 15 % rise in vessel service capacity in Hamburg after full ASC integration. Notably, Dar es Salaam's 41 % reduction in average vessel-quay working time (from 12.6 to 7.4 hours) slightly exceeds these benchmarks, suggesting that ports transitioning from predominantly manual operations can achieve even greater relative gains when first adopting mechanization.

This exceptional performance aligns with Port Competitiveness Theory, which posits mechanization as a foundational driver of terminal productivity and modal attractiveness (Yuen & Wang, 2013). By eliminating labor-intensive single-lift cycles and synchronizing quay-to-yard transfers via real-time scheduling algorithms, ACH systems compress critical path activities and unlock latent handling capacity. The Dar es Salaam experience underscores that even under emerging-market conditions, where infrastructural and institutional constraints exist, the “low-hanging fruit” of crane automation can yield outsized efficiency dividends when thoughtfully implemented.

### 5.2 Contextual Constraints

Despite the marked throughput gains, the moderate challenge ratings ( $M = 3.47$  for power-

outages;  $M = 3.50$  for maintenance delays) reveal enduring operational barriers. Frequent grid interruptions echoed by World Bank (2021) in Mombasa's context force terminals to pause ASC operations or revert to rubber-tyred gantries, thereby negating some mechanization benefits. In Dar es Salaam, stakeholders described unplanned brownouts that halted crane motion mid-cycle, triggering manual workarounds and eroding system reliability.

In addition, the maintenance-delay mean reflects a pronounced “confidence gap” among local technicians, as identified by Joubert (2018). With limited vendor-accredited training programs for ASC and AGV diagnostics, port staff often lack the expertise to perform rapid fault isolation and repair, increasing mean time to repair (MTTR). This skills mismatch not only prolongs downtime but also undermines operator trust in fully automated sequences highlighting the need for targeted capacity-building initiatives alongside technological investments.

### 5.3 Managerial Implications

Given ACH's unique standardized-beta contribution ( $\beta = .278$ ) to the Port-Efficiency Index, the Tanzania Ports Authority should prioritize infrastructure resilience measures. Installing uninterruptible power supplies (UPS) and on-site generation capacity will mitigate the impact of grid volatility, allowing ASCs to complete full lift cycles without interruption. Empirical precedents from Hamburg's automated terminals suggest that robust power-backup arrangements can elevate equipment availability above 95 % (Meisel, 2016).

Concurrently, institutionalizing vendor-certified training programs is essential to close the technician “confidence gap.” Establishing an in-house automation help desk staffed by hybrid engineers skilled in both mechanical and software diagnostics can reduce MTTR and build operator confidence in automated sequences. Drawing on Hamburg's predictive-maintenance protocols, integrating sensor-based health monitoring and automated fault alerts will further streamline

servicing schedules, ensuring that maintenance is both proactive and data-driven.

#### 5.4 Limitations and Future Research

This study's single case-study focus on Dar es Salaam Port imposes constraints on the generalizability of its findings. While benchmarking against ports in Mombasa, Durban, and Singapore bolstered external validity, the unique socio-economic and infrastructural context of East Africa may limit direct transferability to other emerging-market settings. Future research should incorporate multiple ports across varied governance models and cargo mixes to validate the robustness of ACH efficiency gains under differing operational frameworks.

Moreover, the cross-sectional design captures ACH impacts at a single point in time, potentially overlooking dynamic learning-curve effects. Longitudinal studies are needed to track the evolution of operator proficiency, maintenance effectiveness, and system optimizations as ports mature in their automation journeys. Investigating the integration of emerging technologies such as AI-driven crane-path optimization, machine-vision container recognition, and blockchain-enabled logistics would also extend understanding of how next-generation innovations can build upon current ACH foundations.

#### 6. Conclusion:

This study demonstrates that Automated Cargo-Handling systems have been a transformative force at Dar es Salaam Port, yielding a statistically significant 27.8 % unique contribution to overall operational efficiency and precipitating a tangible 41 % reduction in vessel quay time. Stakeholders uniformly praised the speed and reliability gains afforded by twin-lift cranes and AGVs, yet moderate concerns about power stability and maintenance capacity underscore the necessity of complementary investments in resilient energy infrastructure and vendor-accredited training. By triangulating quantitative performance metrics with rich qualitative insights, the research affirms that mechanization serves as a powerful lever for throughput enhancement validating global

benchmarks while also highlighting the critical role of human-capital and support systems in sustaining automation dividends. These findings offer pragmatic guidance for port authorities seeking to expand and optimize their automation roadmaps, ensuring that future gains are both robust and enduring.

#### References:

1. Braun, V., & Clarke, V. (2013). *Successful qualitative research: A practical guide for beginners*. SAGE.
2. Heilig, L., Schwarze, S., & Voß, S. (2017). An analysis of digital transformation in the history of modern ports. *Journal of Shipping and Trade*, 2(1), 5. <https://doi.org/10.1186/s41072-017-0022-5>
3. Joubert, D. (2018). Port automation in emerging economies: A case study of Mombasa Port. *Maritime Economics & Logistics*, 20(3), 321–341. <https://doi.org/10.1057/s41278-017-0092-6>
4. Kothari, C. R. (2004). *Research methodology: Methods and techniques* (2nd ed.). New Age International.
5. Lam, J. S. L., & Yap, W. Y. (2015). Port governance and the role of public–private partnerships in enhanced port performance: A case study of Asia–Pacific region. *Transportation Research Part A: Policy and Practice*, 77, 236–248. <https://doi.org/10.1016/j.tra.2015.04.022>
6. Lee, S. W., & Song, D.-W. (2019). Comprehensive model for the analysis of port efficiency in automation transitions. *Maritime Policy & Management*, 46(2), 153–171. <https://doi.org/10.1080/03088839.2018.1475490>
7. Meisel, F. (2016). The future of port operations: Automated gantries and beyond. *International Journal of Shipping and Transport Logistics*, 8(4), 321–338. <https://doi.org/10.1504/IJSTL.2016.076128>

8. Notteboom, T., & Rodrigue, J.-P. (2008). Containerization, box logistics and global supply chains: The integration of ports and terminals. *Maritime Economics & Logistics*, 10(1–2), 152–174. <https://doi.org/10.1057/palgrave.mel.9100197>
9. Saunders, M., Lewis, P., & Thornhill, A. (2019). *Research methods for business students* (8th ed.). Pearson.
10. Schiller, S., Zimmermann, F., & Mayer, T. (2019). Cybersecurity in port operations: Challenges and best practices. *Journal of Maritime Policy & Management*, 46(6), 744–763. <https://doi.org/10.1080/03088839.2018.1563812>
11. TPA. (2023). *Annual strategic report 2022/23*. Tanzania Ports Authority.
12. World Bank. (2021). *Port performance and automation in Sub-Saharan Africa*. World Bank Publications.
13. Yuen, K. F., & Wang, X. (2013). Port competitiveness: The role of automation and digitalisation. *Transport Reviews*, 33(5), 565–588. <https://doi.org/10.1080/01441647.2013.827884>