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Data-Driven Performance Monitoring in Maritime Logistics: A Framework for Improving Operational Efficiency in Developing-Economy Ports

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***Abstract*—This review examines how data-driven performance monitoring can strengthen operational efficiency in developing-economy ports. It addresses persistent challenges including vessel congestion, prolonged cargo dwell time, equipment downtime, fragmented documentation, weak hinterland connectivity, unreliable electricity, limited digital integration, and institutional coordination failures. The study adopts a structured review approach, synthesising pre-2020 scholarly literature on maritime logistics, port performance measurement, digital technologies, governance, energy resilience, and analytical decision support. The analysis evaluates operational processes, performance indicators, enabling technologies, implementation barriers, and the conditions required for an integrated monitoring framework.**

The findings show that port efficiency cannot be assessed through cargo throughput alone. Effective monitoring requires a balanced portfolio of indicators covering vessel turnaround, berth productivity, crane performance, equipment utilisation, yard occupancy, customs clearance, gate processing, service reliability, safety, environmental performance, and stakeholder satisfaction. The review further establishes that terminal operating systems, port community systems, automatic identification systems, sensors, predictive analytics, simulation tools, blockchain, and real-time dashboards can improve visibility and decision quality when supported by accurate data, interoperable platforms, skilled personnel, resilient power systems, and clear governance arrangements.

The study concludes that sustainable performance improvement depends on linking data collection, analytics, accountability, corrective action, and continuous learning within a phased implementation model. It recommends prioritising data standards, process mapping, staff development, renewable and backup power solutions, cybersecurity, inter-agency collaboration, and measurable pilot projects before advancing toward predictive and prescriptive analytics. The proposed framework provides a practical basis for improving reliability, competitiveness, resilience, and resource utilisation across maritime logistics systems in developing economies while preserving institutional adaptability and financial feasibility under local conditions.

***Keywords*— Maritime logistics; port performance monitoring; operational efficiency; developing economies; digital port technologies; predictive analytics.**

I. INTRODUCTION

Maritime logistics constitutes the connective infrastructure through which global production, consumption and distribution systems are coordinated. Ports are logistics platforms linking shipping lines, terminal operators, customs authorities, freight forwarders, carriers and cargo owners. Their operational performance therefore influences the speed, reliability and cost of supply chains. Evidence from Latin American trade demonstrates that port efficiency is a significant determinant of maritime transport costs and national competitiveness (Sánchez et al., 2003). This relationship is especially consequential for developing economies, where high logistics costs magnify the effects of port delays.

Operational efficiency depends on coordinated management of vessel arrivals, berth allocation, crane deployment, yard storage, container transfers, gate processing and hinterland evacuation. These activities are interdependent: delays can generate congestion, longer vessel turnaround times, excessive cargo dwell times and unreliable schedules. Carlo, Vis and Roodbergen (2014) show that internal terminal transport connects seaside, yard-side and landside operations, making integrated planning essential to productivity. Yet many developing-economy ports manage these interfaces through fragmented systems, manual documentation and retrospective reporting. Such arrangements restrict operational visibility and make it difficult to distinguish temporary disruption from persistent process failure.

Port performance is multidimensional and cannot be represented adequately by cargo throughput alone. Throughput indicates the scale of activity, but it does not reveal whether vessels waited excessively, equipment was underutilised, containers remained too long in storage or users incurred avoidable costs. A logistics and supply-chain perspective therefore requires performance measures that capture time, cost, productivity, reliability, service quality and connectivity across organisational boundaries (Bichou and Gray, 2004). From the user perspective, port charges, service quality, capacity and hinterland connections also shape competitiveness, as demonstrated in the assessment of major Chinese and neighbouring Asian container ports by Yuen, Zhang and Cheung (2012). Effective monitoring must consequently combine operational indicators with measures reflecting customer experience and supply-chain outcomes.

The need for such an approach is particularly pronounced in African ports. Reforms across the continent have sought to increase efficiency, improve trade competitiveness and reduce government expenditure, but outcomes remain uneven because regulatory, institutional and infrastructural conditions differ substantially among port systems (Trujillo, González and Jiménez, 2013). Nigeria illustrates the importance of incorporating service-oriented evidence into port evaluation. Research involving Nigerian ports found gaps between users' expectations and perceptions of service quality, indicating that operational performance should be assessed through physical outputs, responsiveness, reliability and satisfaction (Ugboma et al., 2007). These findings support monitoring systems that connect operational events with stakeholder consequences.

Developing regions are not homogeneous, and port-performance strategies cannot be transferred uncritically from technologically advanced terminals. A comparative analysis of ports across developing regions found substantial variation in productivity and efficiency, with outcomes influenced by private participation, institutional quality, liner connectivity and multimodal links (Suárez-Alemán et al., 2016). A performance-monitoring framework must therefore be sensitive to differences in port size, cargo composition, governance model, digital maturity, labour organisation, hinterland infrastructure and investment capacity. It must also distinguish between inefficiency caused by internal practices and constraints arising from the wider logistics environment.

The measurement challenge is intensified by limitations in available data. Port-efficiency studies commonly apply data envelopment analysis and stochastic frontier analysis, but their findings depend on the suitability, consistency and comparability of selected inputs and outputs. Merkel and Holmgren (2017) caution that much port-efficiency research relies on partial production functions and may not capture substitutions between producer inputs and user-provided resources. Similar weaknesses emerge when managerial indicators are calculated from incomplete records, inconsistent definitions or delayed reports. Data-driven monitoring must therefore begin with clear indicator definitions, reliable collection procedures, common time stamps, auditable data ownership and agreed information-sharing protocols.

Digitalisation provides an opportunity to overcome some of these limitations. Port information systems can integrate operational and administrative processes, improve communication and enhance visibility, reliability, security and decision-making (Heilig and Voß, 2017). Terminal operating systems, automatic identification systems, vessel traffic services, electronic customs platforms, gate technologies and equipment sensors can generate continuous data on vessel movements, berth use, crane activity, yard occupancy, cargo status and truck flows. Consolidated data can support descriptive analysis of completed operations, diagnostic identification of bottlenecks, predictive assessment of likely delays and prescriptive recommendations for resource allocation. However, digital technology creates value only when data are accurate, interoperable and aligned with operational decisions. Open-data principles further extend the potential of port digitalisation by enabling transport information to be reused across organisational and technological boundaries. Inkinen, Helminen and Saarikoski (2019) argue that machine-readable data, particularly information concerning port and hinterland infrastructure, can support visualisation, traffic monitoring and data-based management. For developing-economy ports, complete real-time integration may be financially or technically unrealistic initially. A phased model can begin with standardised static datasets and a limited group of critical indicators before progressing towards automated collection, real-time dashboards, predictive analytics and integrated port-community platforms. This progression allows institutional capability to mature alongside technological investment.

A data-driven framework should convert operational records into actionable intelligence rather than merely producing additional statistics. Core indicators may include vessel waiting time, turnaround time, berth occupancy, crane productivity, equipment availability, yard utilisation, cargo dwell time, customs-release time, truck turnaround time, gate congestion and service reliability. These indicators should be linked to targets, historical baselines and escalation thresholds so that managers can identify deviations promptly and trace them to operational causes. Indicators should also be interpreted collectively because isolated improvements can transfer congestion elsewhere in the logistics chain. Accelerating quay operations, for example, may worsen yard congestion when storage capacity and inland evacuation remain constrained.

Against this background, the present review examines how data-driven performance monitoring can improve operational efficiency in developing-economy ports. It integrates literature on maritime logistics, port efficiency, terminal operations, service quality, information systems and digitalisation to establish the conceptual basis for a context-sensitive framework. The study focuses on the relationship between data availability, performance indicators, analytical capability, institutional coordination and managerial action. Its central premise is that sustainable operational improvement requires more than technology acquisition: it requires governance through which trustworthy data are transformed into shared situational awareness, accountable decisions and continuous process improvement across the port logistics ecosystem.

1.1 Background and Context of Maritime Logistics in Developing Economies

Maritime logistics provides the operational architecture through which seaborne trade is connected to inland production, consumption, and distribution systems. In developing economies, ports perform a particularly strategic role because they often serve as the principal gateways for imports, exports, industrial inputs, food supplies, energy resources, and manufactured goods. Their efficiency therefore has direct implications for national competitiveness, regional integration, investment attraction, and the cost of doing business. Unlike many advanced port systems, however, ports in developing economies frequently operate within environments characterised by infrastructure deficits, fragmented institutions, limited automation, unreliable utilities, constrained capital, and uneven technical capacity.

These conditions intensify the complexity of coordinating vessel arrivals, berth allocation, cargo handling, storage, customs clearance, gate operations, and hinterland evacuation. Operational delays at any stage can generate cumulative disruption across the logistics chain, leading to congestion, prolonged dwell times, higher transport costs, schedule unreliability, and reduced service quality. The growing scale of containerisation, larger vessel capacities, expanding trade volumes, and increased demand for visibility have further exposed the limitations of traditional management approaches based on manual reporting and retrospective assessment.

Data-driven performance monitoring has consequently emerged as a critical mechanism for improving operational awareness and managerial control. By integrating information from terminal systems, vessel tracking technologies, customs platforms, equipment sensors, and transport interfaces, port managers can obtain a more accurate understanding of operational conditions. Such visibility creates a foundation for timely intervention, improved resource allocation, performance accountability, and continuous efficiency improvement within developing-economy maritime logistics systems across increasingly interconnected national, regional, and global trade networks.

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1.2 Statement of the Problem

Despite their economic importance, many developing-economy ports continue to experience persistent operational inefficiencies. Common problems include vessel congestion, prolonged anchorage, inefficient berth allocation, low crane productivity, excessive cargo dwell time, yard overcrowding, equipment downtime, documentation delays, and unreliable inland evacuation. These difficulties are compounded by fragmented institutional responsibilities, weak coordination, inconsistent operating procedures, and limited capacity to identify the precise causes of performance failure.

A central problem is the inadequate use of operational data in planning, control, and decision-making. In many ports, information is collected through disconnected systems, manual records, or periodic reports that become available only after delays have occurred. Data definitions may differ across agencies, records may be incomplete, and access may be restricted by organisational silos. Consequently, port authorities and terminal operators often lack a unified, real-time view of vessel movements, cargo flows, equipment utilisation, customs processing, gate activity, and hinterland conditions. This limits their ability to detect emerging bottlenecks, compare performance against targets, forecast disruptions, and implement timely corrective action.

The absence of an integrated monitoring framework also encourages reliance on isolated indicators, particularly total cargo throughput, which may conceal underlying inefficiencies. A port may record increasing volumes while simultaneously experiencing longer waiting times, worsening congestion, or declining service reliability. Without an analytical structure linking data, indicators, operational processes, and managerial responses, digital investments may produce additional information without generating measurable improvement. The problem addressed by this review is therefore the need for a coherent, context-sensitive framework that transforms fragmented port data into actionable intelligence for sustained operational efficiency.

1.3 Aim, Objectives, and Review Questions

This review aims to develop a context-sensitive framework for data-driven performance monitoring that can support improvements in the operational efficiency of developing-economy ports. The study is premised on the view that port reform requires more than the acquisition of technologies. It requires an approach through which data are collected, standardised, analysed, interpreted, and translated into managerial action across the maritime logistics system.

The first objective is to examine the operational structure of maritime logistics and identify the principal sources of inefficiency affecting vessel, terminal, yard, gate, customs, and hinterland activities. The second objective is to evaluate the performance indicators most suitable for measuring time, productivity, reliability, asset utilisation, cost, safety, and service quality. The third objective is to assess the data sources, information systems, analytical methods, and digital technologies capable of supporting effective performance monitoring. The fourth objective is to analyse the institutional, financial, infrastructural, regulatory, and human-capital conditions that influence implementation in developing economies. The final objective is to synthesise these elements into a phased framework for operational monitoring, early warning, decision support, accountability, and continuous improvement.

The review is guided by several questions. Which operational indicators provide the most accurate representation of port efficiency? How can fragmented data from multiple stakeholders be integrated into a reliable monitoring system? What analytical tools can convert operational records into timely and actionable insights? Which barriers are most likely to constrain implementation in resource-limited ports? Finally, how can global digital-port practices be adapted without disregarding local infrastructure, governance, financial capacity, workforce readiness, and operational realities?

1.4 Scope, Significance, and Organisation of the Review

This review examines data-driven performance monitoring within the operational environment of developing-economy ports. Its scope covers the activities that shape maritime logistics performance, including vessel arrival management, berth planning, cargo handling, yard operations, equipment deployment, customs processing, gate management, and inland cargo evacuation. It considers the roles of port authorities, terminal operators, shipping lines,

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customs agencies, freight forwarders, transport providers, cargo owners, regulators, and technology partners. Although the emphasis is operational efficiency, the review recognises that productivity is connected to service reliability, safety, cost control, environmental performance, and customer experience.

The significance of the study lies in its attempt to bridge the divide between port digitalisation and measurable operational improvement. Technology initiatives may prioritise system acquisition without establishing performance objectives, data standards, or decision-making responsibilities. By organising indicators, data sources, analytical methods, governance requirements, and improvement mechanisms within a framework, the review provides a basis for designing monitoring systems that reflect resource conditions of developing economies. The framework is intended to assist policymakers, port managers, terminal operators, investors, researchers, and development institutions in prioritising interventions and evaluating their results.

The review is organised into seven major sections. Following the introduction, the discussion examines maritime logistics operations and performance challenges, the principles of data-driven monitoring, key efficiency indicators, enabling digital technologies, and the proposed monitoring framework. The final substantive section evaluates implementation barriers, enabling conditions, and future research priorities. This structure progresses from problem definition to conceptual development, technological application, framework design, and practical implementation, thereby maintaining a coherent analytical sequence throughout the paper.

II. MARITIME LOGISTICS OPERATIONS AND PERFORMANCE CHALLENGES IN DEVELOPING-ECONOMY PORTS

Maritime logistics operations encompass the coordinated movement of vessels, cargo, equipment, information and inland transport through port systems. In developing economies, these operations are consequential because seaports frequently function as dominant gateways for trade. Their performance therefore influences industrial production, consumer prices, export competitiveness, food security and global value-chain participation. Port efficiency cannot be judged solely by cargo throughput, since performance also depends on how reliably maritime services connect with terminal activities, customs procedures, storage facilities and hinterland transport. Bichou and Gray (2004) accordingly conceptualise port performance as a supply-chain issue in which outcomes emerge from interactions among multiple organisations rather than terminal productivity alone.

The operational cycle begins before a vessel enters the harbour. Effective port-call management requires arrival information, pilotage coordination, tug availability, channel access, berth assignment and suitable labour and equipment preparation. When these activities are poorly synchronised, vessels remain at anchorage, incur fuel costs and disrupt schedules. Notteboom (2006) identifies port congestion and uncertain cargo-handling times as important pressures on liner-service reliability, demonstrating that port delays affect the wider maritime network. Such difficulties are often more severe in developing-economy ports, where limited berth capacity, shallow navigation channels, ageing marine equipment, inflexible work arrangements and unreliable communication systems restrict the ability to accommodate fluctuating arrivals efficiently.

After berthing, performance depends on crane availability, labour deployment, stowage planning and uninterrupted cargo transfer between ship and shore. Container-terminal operations are interdependent because quay handling, horizontal transport and yard management must be coordinated as a unified process. Carlo, Vis and Roodbergen (2014) show that inefficiencies in internal terminal transport can quickly propagate across seaside, yard-side and landside activities. A delay in tractor assignment, for example, can reduce crane productivity, increase berth occupancy and create yard congestion. In many developing ports, outdated equipment, weak preventive maintenance, shortages of spare parts and limited technical expertise further reduce operational continuity and asset utilisation.

Yard operations constitute a major source of inefficiency. Containers must be stacked, located, retrieved and transferred in a manner that supports vessel schedules and timely inland evacuation. Poor planning increases rehandling, consumes equipment hours and contributes to excessive dwell time. High yard occupancy can reduce safety and limit access to priority cargo. These problems become acute where customs clearance is slow, documentation remains paper-based and importers delay cargo collection. The resulting congestion may affect gate operations, increase truck queues and reduce terminal capacity. The technical-efficiency literature demonstrates that port performance depends not only on infrastructure quantity but also on how effectively labour, capital and land are converted into cargo-handling outputs (Cullinane et al., 2006).

Hinterland connectivity is important because port productivity is constrained when cargo cannot move efficiently beyond the terminal. Weak road networks, limited rail services, urban traffic congestion, informal trucking practices and poorly coordinated gate systems frequently extend cargo dwell times. Clark, Dollar and Micco (2004) demonstrate that port inefficiency raises maritime transport costs and reduces trade, showing that operational deficiencies have consequences beyond the port boundary. In developing economies, these effects are amplified by dependence on imported inputs and limited alternative gateways. Even when quayside productivity improves, inadequate inland evacuation can merely shift congestion from the berth to the yard or gate.

Institutional fragmentation complicates maritime logistics operations. Port authorities, terminal operators, customs agencies, shipping lines, freight forwarders, security services and transport providers may pursue different priorities and maintain separate information systems. Where responsibilities overlap or communication is weak, cargo release and vessel processing become vulnerable to duplication, inconsistent procedures and delayed decisions. African port reforms have introduced private participation and new governance arrangements, yet outcomes vary because institutional capacity, regulation and infrastructure differ across countries (Trujillo, González and Jiménez, 2013). Reform therefore cannot be assessed solely by ownership structure; operational coordination, accountability and data-sharing capability remain essential.

Performance challenges vary across developing regions. Suárez-Alemán et al. (2016) found substantial differences in container-port efficiency associated with institutional quality, private-sector participation, liner connectivity and multimodal infrastructure. This variation means that labels such as “developing ports” can conceal important differences in scale, cargo composition, governance, digital maturity and resource availability. A performance-improvement strategy appropriate for a large transshipment hub may be unsuitable for a smaller gateway port serving a landlocked hinterland. Context-sensitive monitoring is therefore necessary to identify whether delays originate from marine access, terminal processes, border administration, equipment constraints or inland transport.

Service quality represents a critical dimension. Operational efficiency must ultimately be reflected in predictable, responsive and reliable services for port users. In Nigeria, Ugboma et al. (2007) identified gaps between users’ expectations and perceptions of port-service quality, indicating that throughput statistics alone do not capture the experience of shipping lines, freight forwarders and cargo owners. Delayed documentation, poor communication, inconsistent procedures and weak complaint resolution can undermine confidence even when physical cargo volumes rise. Performance monitoring should consequently incorporate customer-oriented measures alongside conventional indicators such as vessel turnaround, berth occupancy and crane productivity.

Reliable data remain fundamental to understanding these challenges. Many developing-economy ports depend on manual records, fragmented spreadsheets and periodic reports that do not provide current operational visibility. Heilig and Voß (2017) explain that port information systems can integrate administrative and operational processes, improve visibility and support coordinated decisions. However, technology adoption alone does not guarantee improvement. Data must be accurate, standardised, timely and accessible to authorised stakeholders. Without agreed definitions and reporting responsibilities, performance indicators may be inconsistent, difficult to compare and vulnerable to manipulation.

Efficiency analysis provides useful diagnostic methods, but its results depend on appropriate data and contextual interpretation. Kammoun (2018), examining Tunisian ports, demonstrates that analytical techniques can produce different efficiency scores. This reinforces the need to treat performance measurement as a managerial tool rather than an automatic ranking exercise. For developing-economy ports, the challenge is to establish monitoring arrangements that connect operational data with practical decisions. Such arrangements should identify bottlenecks, distinguish structural constraints from managerial failures, support resource prioritisation and enable timely action. By integrating vessel, terminal, yard, customs, gate and hinterland information, ports can move from retrospective reporting toward continuous performance control and more reliable maritime logistics.

III. PRINCIPLES AND COMPONENTS OF DATA-DRIVEN PERFORMANCE MONITORING

Data-driven performance monitoring in maritime logistics is founded on the conversion of operational records into evidence for planning, control and continuous improvement. Its purpose is not merely to accumulate information, but to establish a relationship among strategic objectives, measurable indicators, analytical interpretation and managerial action. In developing-economy ports, this distinction is essential because technology investments can remain disconnected from priorities when implementation is driven by equipment acquisition rather than performance needs. Effective monitoring must therefore begin with defined questions concerning vessel flow, berth utilisation, cargo handling, yard congestion, gate processing, customs release, equipment reliability and hinterland evacuation (Fruth and Teuteberg, 2017).

The first principle is strategic alignment. Every monitored variable should correspond to an operational objective and a decision for which authority exists. Data on vessel waiting time, for example, become valuable when they are linked to berth-planning standards, service commitments, escalation thresholds and corrective responsibilities. Similarly, equipment utilisation data should inform maintenance scheduling, replacement decisions and labour deployment rather than appear in reports. Waller and Fawcett (2013) emphasise that data science and predictive analytics create value when analytical capabilities are connected to relevant managerial problems. Port monitoring should therefore prioritise decision usefulness over uncontrolled dataset expansion.

A second principle is end-to-end process visibility. Maritime logistics performance emerges from interdependent activities undertaken by port authorities, terminal operators, customs agencies, shipping lines, freight forwarders, transport companies and cargo owners. Monitoring limited to one organisation can misdiagnose bottlenecks because delays may migrate between anchorage, berth, yard, gate and hinterland interfaces. Heilig and Voß (2017) show that seaport information systems support operational and administrative functions across domains. A coherent monitoring architecture must consequently map data to the cargo and vessel journey, establish common event definitions and identify dependencies among physical movements, documentary processes and stakeholder decisions.

The data-acquisition component should integrate information from terminal operating systems, automatic identification systems, vessel traffic services, customs platforms, gate systems, equipment sensors, electronic manifests, truck records and infrastructure databases. Each source contributes a partial representation of port activity and must be associated with consistent identifiers and time stamps. Inkinen, Helminen and Saarikoski (2019) demonstrate that machine-readable transport and infrastructure data can support visualisation and data-based management, particularly when information is made accessible for reuse. Developing-economy ports may begin with standardised static datasets and incorporate near-real-time feeds as connectivity, institutional capability and system maturity improve.

Data quality is the foundation of credible performance monitoring. Completeness, accuracy, consistency, timeliness, validity and traceability determine whether analytical results can support operational decisions. Missing arrival times, inconsistent container identifiers or delayed equipment records can distort turnaround estimates, productivity ratios and congestion forecasts. Hazen et al. (2014) argue that analytical decisions are only as reliable as the underlying data and advocate monitoring and control of data quality. Ports should therefore define validation rules, reconcile conflicting records, document data lineage, assign custodianship and establish exception procedures. Quality assurance should operate throughout data creation, transmission, storage, transformation and reporting rather than after dashboards have been produced.

Indicator design constitutes a component. Measures must be relevant, comparable, actionable and resistant to manipulation. A balanced system should combine input indicators, process indicators, output measures and outcome measures. Infrastructure availability and labour hours describe inputs; crane productivity and customs-processing time represent processes; cargo throughput and vessel turnaround capture outputs; while reliability, user satisfaction and logistics cost reflect outcomes. Evidence from Nigerian ports demonstrates that service quality and satisfaction provide information not visible in physical productivity statistics (Ugboma et al., 2007). Accordingly, data-driven monitoring should integrate operational efficiency with user-oriented measures to prevent narrow optimisation that overlooks service consequences.

Analytical capability should progress through descriptive, diagnostic, predictive and prescriptive stages. Descriptive analytics establish what occurred through trends, ratios and dashboard summaries. Diagnostic analysis investigates why deviations occurred by comparing processes, locations, shifts, equipment and stakeholder actions. Predictive models estimate likely congestion, equipment failure, cargo dwell time or truck demand. Prescriptive methods evaluate alternative interventions and recommend resource allocations. Gunasekaran et al. (2017) associate the assimilation of big data and predictive analytics with improved supply-chain and organisational performance. For ports, however, increasingly sophisticated models should be adopted only when data quality, interpretability and managerial capacity are sufficient to support dependable use.

Real-time and exception-based monitoring are particularly valuable in environments where delays propagate rapidly. Continuous feeds can reveal unexpected vessel arrivals, crane stoppages, rising yard occupancy, gate queues or interrupted inland connections before they become systemic disruptions. The monitoring system should compare current conditions with operational thresholds and issue differentiated alerts according to urgency, likely impact and responsible unit. Hofmann and Branding (2019) illustrate how Internet of Things data, cloud services and simulation-based forecasts can support real-time decisions in port truck dispatching. Such capabilities enable managers to shift from retrospective explanation toward anticipatory coordination, provided alerts are accurate and linked to feasible interventions.

Dashboards form the communication layer between data and decision-makers. Their design should reflect user roles rather than present identical information to all stakeholders. Executives require strategic trends and risk exposure, terminal managers need current bottlenecks and resource status, while equipment supervisors require maintenance and availability indicators. Visualisations should show targets, variance, historical context and causal relationships without overwhelming users with unnecessary detail. Kache and Seuring (2017) note that digital information offers supply-chain opportunities but also generates organisational and technical challenges. Dashboard usefulness therefore depends on clarity, shared definitions, user training and confidence that displayed information accurately represents operational reality.

Governance provides the institutional structure through which monitoring remains trustworthy and sustainable. Port stakeholders must agree on data ownership, access rights, reporting responsibilities, retention periods, confidentiality, cybersecurity and acceptable secondary use. Interoperability standards are required so that different systems can exchange information without repeated manual re-entry. Governance should also protect commercial sensitivity while enabling sufficient transparency for coordinated operations and public accountability. Fruth and Teuteberg (2017) identify data abuse and cybercrime among the risks accompanying maritime digitalisation. Accordingly, authentication, access control, audit trails, backup arrangements and incident-response procedures are integral components of performance monitoring rather than separate technical considerations.

Performance measurement must also recognise methodological limitations. Efficiency scores and benchmarks depend on the variables, comparison groups, time periods and analytical models selected. Kammoun's (2018) assessment of Tunisian ports demonstrates that data envelopment analysis and stochastic frontier analysis can produce different estimates from the same operational setting. Monitoring systems should therefore avoid treating a single composite score as an unquestionable representation of performance. Managers should examine underlying indicators, contextual

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constraints and sensitivity to methodological choices. Benchmarking is most defensible when peer ports share comparable cargo structures, infrastructure conditions and institutional environments, and when quantitative findings are interpreted alongside operational knowledge.

Finally, data-driven monitoring should operate as a learning cycle linking measurement, review, intervention and reassessment. Performance meetings should examine deviations, test causal explanations, assign actions and evaluate whether interventions deliver sustained improvement. Analytical insights must be embedded in routines, incentives and professional judgement; otherwise, digital platforms may become reporting repositories with limited operational influence. Developing-economy ports should adopt a phased architecture that begins with priority processes, reliable indicators and basic governance before expanding toward predictive analytics, open-data integration and digital twins. This sequencing reflects the evidence that technological assimilation, organisational capability and data maturity must develop together if monitoring is to improve maritime logistics performance (Gunasekaran et al., 2017).

IV. KEY PERFORMANCE INDICATORS FOR MARITIME LOGISTICS EFFICIENCY

Key performance indicators provide the measurement architecture through which maritime logistics efficiency can be measured and improved. In developing-economy ports, their value lies in translating vessel, terminal, customs, gate and hinterland activities into evidence for operational control. An effective system extends beyond throughput because volume alone cannot reveal productive resource use or user exposure to delay, uncertainty and avoidable cost. Bichou and Gray (2004) argue that port performance should be assessed from a logistics and supply-chain perspective, requiring indicators that reflect terminal operations and relationships across the wider transport network.

Indicator selection should begin with strategic relevance. Each measure must correspond to a defined objective, process and accountable decision-maker. Indicators should be measurable, timely, comparable and sensitive to operational change. They should also discourage local optimisation that creates adverse consequences elsewhere. Increasing quay productivity offers limited system benefit when containers accumulate because customs clearance or inland evacuation remains slow. Ha et al. (2017) demonstrate that port performance measures are interdependent and that stakeholders assign different importance to operational, financial, service and connectivity outcomes. KPI design must therefore balance managerial priorities with user expectations and system-wide efficiency.

Vessel and berth indicators are fundamental because ship delays generate costs and disturb liner schedules. Pre-berthing waiting time measures the period between arrival and berth availability, while vessel turnaround time records the duration from port arrival to departure. Berth occupancy indicates the proportion of available berth time in use, whereas berth productivity relates cargo handled to time alongside. These measures require joint interpretation: high occupancy accompanied by rising waiting time may indicate capacity pressure, poor berth planning or arrival variability. Notteboom (2006) emphasises that port time and schedule reliability are central to liner-service performance, making waiting, service and turnaround indicators critical for diagnosing maritime interface efficiency.

Cargo-handling productivity indicators evaluate how effectively labour and equipment convert available time into output. Common measures include gross and net crane moves per hour, tonnes handled per ship-hour, gang productivity, equipment availability, equipment utilisation and labour output per shift. Gross productivity captures total elapsed working time, whereas net productivity excludes designated interruptions and exposes operational inefficiencies more precisely. However, productivity must not be pursued at the expense of safety, cargo integrity or downstream flow. Cullinane et al. (2006) show that technical efficiency depends on relationships between inputs and outputs, supporting complementary indicators rather than isolated production totals.

Yard performance is important because storage congestion can constrain the terminal. Container dwell time, yard occupancy, stacking density, rehandling rate, retrieval accuracy and average storage duration reveal whether cargo is moving or immobilised. Excessive dwell time may reflect delayed customs release, importer behaviour, documentation errors, inadequate trucking capacity or inefficient terminal procedures. Yard occupancy should be monitored against thresholds because performance can deteriorate as available space becomes constrained. Where land expansion is difficult, reducing storage and rehandling may produce greater efficiency gains than infrastructure enlargement.

Gate and hinterland indicators extend performance measurement beyond the terminal. Truck turnaround time, gate transaction time, queue length, appointment compliance, rail utilisation, modal split and cargo evacuation rate show whether landside capacity matches waterside production. Munim and Schramm (2018) establish that port infrastructure and logistics performance contribute to trade and economic outcomes, reinforcing connectivity indicators. A terminal may record strong crane productivity while the logistics chain remains inefficient because vehicles wait for hours, rail services are unreliable or corridor congestion delays delivery. End-to-end monitoring is therefore required to prevent bottleneck displacement.

Customs and documentary indicators are especially significant in developing economies, where administrative delays can exceed physical handling time. Relevant measures include declaration-processing time, inspection frequency, cargo-release time, electronically processed documents, error rates and the interval between discharge and clearance. These indicators should distinguish unavoidable regulatory controls from duplication, inconsistent procedures and preventable waiting. Suárez-Alemán et al. (2016) show that institutional quality contributes to differences in developing-region port efficiency. Operational dashboards should therefore integrate customs and terminal milestones so administrative bottlenecks are visible alongside physical cargo movements.

Cost, reliability and service-quality indicators connect operational performance with user outcomes. Handling cost per unit, demurrage exposure, storage charges, schedule adherence, cargo damage, claims frequency, complaint-resolution time and customer satisfaction indicate whether improvements create value. Nigerian port research by Ugboma et al. (2007) demonstrates that users assess performance through reliability, responsiveness and service quality. These measures are necessary because a port can increase throughput while users encounter unpredictable procedures, poor communication and costly delay. Satisfaction indicators should complement objective operational data rather than replace them.

Safety and environmental performance should be incorporated because productive operations are not sustainable when they increase accidents, emissions or resource waste. Suitable indicators include injury frequency, equipment incidents, hazardous-cargo events, fuel consumption, energy use per cargo unit, greenhouse-gas emissions, air pollutants, spills, waste recovery and noise exposure. Lim et al. (2019) demonstrate that port sustainability assessment increasingly integrates operational, environmental and social dimensions. These measures encourage managers to evaluate productivity improvements against wider consequences and identify practices that reduce delay and environmental burden.

Benchmarking and composite assessment can convert numerous indicators into structured intelligence, but methodological caution is essential. Historical baselines reveal trends, while peer benchmarking enables comparison with terminals of similar scale, cargo structure and operating conditions. Kammoun (2018) shows that different efficiency techniques can yield different results, indicating that rankings depend on model assumptions and variable selection. Yuen, Zhang and Cheung (2012) further demonstrate that competitiveness is shaped by user-oriented factors, including service, charges, capacity and connectivity. Balanced scorecards should retain underlying measures rather than conceal them within a single index.

A credible KPI system depends on data quality, definitions and disciplined review. Indicator owners should specify formulas, units, frequency, sources, targets and escalation thresholds. Dashboards should show values, historical variation and relationships among vessel, cargo, yard, gate and customer outcomes. Managers should investigate deviations, assign corrective actions and evaluate results. In developing-economy ports, phased implementation is appropriate: a limited set of reliable indicators should precede complex indices or prediction tools. This approach ensures that monitoring becomes a governance mechanism through which evidence informs accountability, resource allocation and continuous maritime logistics improvement.

V. DIGITAL TECHNOLOGIES AND ANALYTICAL TOOLS FOR PORT PERFORMANCE MONITORING

Digital technologies have transformed port performance monitoring from periodic reporting into continuous observation, interpretation and intervention. They connect vessel movements, cargo flows, equipment status, documentary procedures and hinterland activity within a common information environment. In developing-economy ports, where fragmented records and delayed communication conceal congestion, digital systems can reveal operational conditions when decisions are required. Technology is not an independent solution; its contribution depends on data quality, institutional coordination, workforce capability, reliable infrastructure and the use of analytical outputs in routine management.

Terminal operating systems provide the central transactional platform for coordinating berth plans, crane assignments, yard locations, equipment movements and gate processes. Electronic information and computer-supported planning can reduce unnecessary container movements and improve terminal productivity compared with operations lacking integrated technologies (Kia, Shayan and Ghotb, 2000). Contemporary implementations consolidate event records and generate indicators for vessel turnaround, crane productivity, yard occupancy, dwell time and equipment utilisation. Operational events must be recorded consistently, time-stamped accurately and linked to common vessel, container and equipment identifiers.

Port community systems broaden visibility beyond the terminal by enabling shipping lines, customs agencies, port authorities, freight forwarders, hauliers and cargo owners to exchange information electronically. Such platforms reduce repeated entry and create a shared record of documentary and physical milestones. Tsamboulas, Moraiti and Lekka (2012) demonstrate that port community system implementation should be evaluated through measurable changes in port performance rather than technical installation alone. Carlan, Sys and Vanelslander (2016) similarly emphasise the need to assess benefits and costs across participating actors. Phased implementation may begin with vessel notices, manifests, customs declarations and cargo-release messages before expanding to payments, appointments and predictive services.

Automatic Identification System data provide a continuous source of information on vessel identity, position, speed, course and movement history. Integrated with berth schedules and terminal records, AIS supports arrival prediction, anchorage monitoring, traffic analysis and port-call reliability assessment. Yet digital abundance does not guarantee analytical validity. Harati-Mokhtari et al. (2007) identify reliability problems associated with incomplete, inaccurate or manually entered AIS information. Port systems must validate vessel data, reconcile conflicting records and distinguish operational anomalies from transmission errors. This is especially important when alerts or forecasts influence pilotage, berth allocation and resource deployment.

Sensor networks, radio-frequency identification and context-aware systems extend monitoring to containers, vehicles and handling equipment. Ngai et al. (2011) developed an intelligent decision-support prototype using ubiquitous sensor technology for real-time observation of container-terminal operations. Similar architectures capture equipment location, condition, container status, gate passage and environmental conditions. They reduce dependence on manual updates while enabling exception-based management. Alerts can be generated when equipment remains inactive, containers enter unauthorised areas, reefer temperatures deviate from limits or yard occupancy approaches critical thresholds. Sensor deployment requires maintenance, communication coverage, device security and clear responsibility for detected exceptions.

Analytical tools convert accumulated data into explanations and forward-looking decisions. Descriptive dashboards show trends and ratios; diagnostic analytics explain deviations; predictive models estimate congestion, equipment failure, vessel delay or cargo dwell time; and prescriptive models compare interventions. Zerbino et al. (2019) show how process mining can reveal inefficiencies in maritime information and document flows by reconstructing actual processes from event logs. This is valuable where formal procedures differ from practice. Managers can identify repeated rework, waiting points, process variants and organisational handoff delays.

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Simulation and optimisation tools complement historical analytics by testing prospective operational choices. They can model berth allocation, crane deployment, yard configuration, gate demand and the effects of larger vessels without disrupting live operations. Digital experimentation is important where infrastructure investment is costly and errors are difficult to reverse. A monitoring platform can supply simulation models with actual arrival patterns, service times and equipment availability, improving realism and enabling scenario comparison. Recommendations must remain interpretable because technically optimal outputs may be impractical under labour rules, safety requirements, customs processes or stakeholder commitments.

Blockchain offers a different capability by creating distributed, tamper-resistant records for transactions shared among organisations. In maritime logistics, potential applications include bills of lading, cargo provenance, customs documentation, release authorisation and milestone verification. Tijan et al. (2019) argue that blockchain may reduce multiple data entry, errors and delays in logistics, although implementation faces technological, organisational and regulatory challenges. For port monitoring, blockchain should be applied selectively where trust, auditability and cross-organisational verification are genuine problems. It does not replace operational databases, sensors or analytics, and its value declines when participants submit inaccurate source data.

Evidence from Tanzania demonstrates that information-system usage can strengthen port logistics performance through lower costs, improved delivery reliability, greater trade activity and enhanced organisational capability (Mlimbila and Mbamba, 2018). This evidence links technology usage with logistics outcomes rather than assuming benefits from adoption. Digital innovation depends on cooperation among actors with different incentives. Carlan et al. (2017) find that port-sector innovation is shaped by barriers and facilitators affecting collaboration, implementation and value capture. Governance arrangements should consequently define data ownership, interoperability standards, access rights, cybersecurity responsibilities and performance-accountability mechanisms.

Physical infrastructure determines whether monitoring remains dependable. Servers, sensors, networks, control rooms and automated gates require stable electricity, maintenance capability and secure connectivity. Nigeria's persistent energy constraints illustrate why digital transformation strategies must incorporate resilient power provision and energy management rather than treating electricity as an external assumption (Oyedepo, 2012). Ports facing such constraints may prioritise cloud services, redundant communications, backup generation and modular systems that can continue essential functions during disruption. Investment decisions should consider lifecycle support, local skills and replacement components.

An effective architecture should integrate operational platforms, community systems, tracking technologies, analytical engines and dashboards through standardised interfaces. Implementation should proceed from clearly defined performance problems, not technological fashion. Ports should establish reliable core datasets, automate priority processes, validate information quality and train managers before adopting more complex prediction or distributed-ledger applications. The ultimate test of any tool is whether it shortens detection time, improves decision quality, strengthens accountability and produces sustained gains in vessel, cargo, equipment and hinterland performance. Performance benefits should be reviewed against baseline indicators so that managers can distinguish genuine operational improvement from simple digitisation of inefficient existing procedures overall.

VI. A DATA-DRIVEN PERFORMANCE MONITORING FRAMEWORK FOR DEVELOPING-ECONOMY PORTS

A data-driven performance monitoring framework for developing-economy ports must integrate operational processes, information architecture, analytical capability, infrastructure resilience and accountable managerial action. Its purpose is not merely to digitise existing reports, but to create a mechanism through which port authorities and logistics stakeholders can identify deviations, diagnose causes, coordinate interventions and verify improvement. Performance measures should emerge from operational objectives and be reviewed as conditions change rather than maintained as static statistical inventories (Neely, Gregory and Platts, 1995). The framework proposed here is adaptive, context-sensitive and suitable for ports operating at different levels of institutional, technological and infrastructural maturity.

The first layer is strategic governance. Port authorities and organisations should define outcomes, including reduced vessel waiting time, improved berth productivity, shorter cargo dwell time, higher equipment availability, faster customs release and inland evacuation. Each objective should be translated into measurable targets, reporting intervals and assigned responsibilities. Ferreira and Otley (2009) emphasise that performance systems require alignment among objectives, strategies, targets, evaluation processes and information flows. In port environments, this alignment must extend across terminal operators, customs agencies, shipping lines, freight forwarders, transport companies, security services and regulators. A governance charter should specify who creates, validates, accesses and acts upon each category of performance information.

The second layer involves stakeholder and process mapping. Maritime logistics performance is generated through linked activities rather than isolated functions. Panayides and Song (2009) demonstrate that port integration within global supply chains depends on coordination, information exchange and value-adding practices. The framework should map vessel arrival, pilotage, berthing, cargo handling, yard storage, customs processing, gate release and hinterland evacuation as connected event chains. This structure allows managers to identify the origin of delays and prevents one stakeholder from improving its own indicator by shifting congestion elsewhere. Hinterland operations must be incorporated because port development increasingly extends beyond terminal boundaries into inland distribution networks (Notteboom and Rodrigue, 2005).

A third layer should establish the data architecture. Information may be acquired from terminal operating systems, automatic identification systems, customs platforms, gate records, equipment logs, truck-management systems, financial records and stakeholder feedback channels. Common identifiers, synchronised time stamps and standard definitions are necessary to connect these sources. Validation procedures should address missing values, duplicate transactions, contradictory event times and unauthorised alterations. DeLone and McLean (2003) show that information-system success depends on system quality, information quality, service quality, use, user satisfaction and resulting benefits. Accordingly, a functional platform remains inadequate when users distrust its data, receive poor support or fail to incorporate its outputs into operational decisions.

The fourth layer converts validated data into a balanced portfolio of indicators. These should include vessel waiting and turnaround time, berth occupancy, crane productivity, equipment utilisation, yard occupancy, cargo dwell time, customs-release time, gate processing, truck turnaround, service reliability, cargo damage and stakeholder satisfaction. Each indicator requires a formula, source, reporting frequency, target and escalation threshold. Evidence from Lagos ports shows that infrastructure deficiencies, institutional weaknesses and coordination failures can affect efficiency (Ojadi and Walters, 2015). Consequently, the framework should capture not only physical productivity but also administrative and governance constraints. African port productivity also varies across facilities, reinforcing context-sensitive benchmarking rather than universal comparison (Barros, 2012).

The analytical layer should progress from descriptive reporting to diagnostic, predictive and prescriptive decision support. Descriptive analytics establish what occurred; diagnostic analysis examines why performance departed from expectations; predictive models estimate likely congestion, equipment failure, vessel delay or cargo dwell time; and prescriptive tools compare interventions. Popovič et al. (2012) demonstrate that business-intelligence maturity and an analytical decision-making culture influence whether information is used effectively. Developing-economy ports should match analytical sophistication to data quality, staff competence and managerial readiness. Complex models that cannot be interpreted, maintained or operationally applied may create an appearance of modernisation without improving decisions.

Dashboards and alert mechanisms form the communication layer. Executive dashboards should present trends, service risks and resource constraints, while operational dashboards should display vessel status, equipment availability, yard conditions,

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documentation progress and gate queues. Alerts should be triggered by defined thresholds and directed to officials with authority to intervene. Visualisations should provide historical baselines, targets, variance and probable consequences. Their design should prevent information overload and distinguish temporary fluctuations from persistent process failures. Performance reviews should document corrective actions, assign responsibility, establish deadlines and evaluate whether interventions produced improvement or transferred delay elsewhere in the logistics chain.

The framework must include an infrastructure-resilience layer because data platforms, sensors, communication networks, servers and control rooms require dependable electricity. Evidence from Nigerian small-scale manufacturing indicates that solar integration can support operations affected by unreliable conventional power supply (Sunday and Omoegun, 2018). Although this evidence is not port-specific, it demonstrates the relevance of alternative power arrangements in resource-constrained operational environments. For developing-economy ports, hybrid energy systems, backup generation, modular storage and protected power supply may be necessary to sustain real-time monitoring and prevent data loss during grid interruptions.

Electrical reliability also depends on how available power is distributed among critical systems. Sunday and Omoegun (2019) show that optimising load distribution improves the effective use of hybrid solar installations in developing-economy settings. Applied cautiously to port monitoring, this supports prioritising electricity for data servers, communication equipment, security systems, smart gates, sensors and operational control platforms. Power architecture should be treated as part of the monitoring framework rather than as an external technical assumption. Energy performance indicators, redundancy protocols and recovery procedures should be included so managers understand how electricity disruptions affect data continuity and decision responsiveness.

Implementation should follow a phased maturity pathway. The first phase establishes governance, process definitions, resilient power requirements and a limited set of reliable indicators. The second integrates priority systems and introduces role-specific dashboards. The third adds automated alerts, diagnostic analytics and benchmarking. The fourth develops predictive and prescriptive capabilities across the port community. Progress should be evaluated through data completeness, system availability, user adoption, decision-response time, operational improvement and stakeholder benefit. This sequencing ensures that technological expansion remains anchored to institutional capability, infrastructure reliability and measurable maritime logistics performance rather than becoming an isolated digitisation initiative.

VII. IMPLEMENTATION CHALLENGES, ENABLING CONDITIONS, AND FUTURE RESEARCH DIRECTIONS

Implementing data-driven performance monitoring in developing-economy ports is constrained by technological, institutional, financial and human-capital conditions that extend beyond the acquisition of digital platforms. Many ports operate with fragmented databases, manual documentation, ageing equipment, unstable connectivity and inconsistent performance definitions. These conditions weaken data completeness, comparability and timeliness, thereby reducing confidence in analytical outputs. Governance structures may compound the problem when agencies retain separate mandates and resist information sharing. Brooks and Pallis (2008) demonstrate that port reform outcomes depend on both governance processes and performance arrangements, indicating that digital monitoring must be embedded within clear institutional responsibilities rather than introduced as an isolated technical project.

Institutional diversity presents a further challenge. Governance models transferred from advanced ports may not fit local legal traditions, political incentives or administrative capabilities. Ng and Pallis (2010) show that apparently generic reforms produce implementation asymmetries because national institutions shape organisational behaviour. Similarly, Notteboom, de Langen and Jacobs (2013) explain that established routines and path dependence can restrict the development of new port capabilities. Developing-economy ports may therefore experience resistance from agencies, terminal operators and employees whose authority, revenue or work practices are affected by greater transparency. Effective implementation requires negotiated data-sharing agreements, defined decision rights, independent oversight and phased adjustment of legacy procedures.

Stakeholder coordination is especially important because port performance is produced collectively. Shipping lines, customs services, terminal operators, freight forwarders, transport companies and cargo owners may hold conflicting interests or different interpretations of efficiency. De Langen (2006) argues that port clusters require governance mechanisms capable of managing collective-action problems. Monitoring arrangements should consequently establish common indicator definitions, interoperable data standards, escalation protocols and forums where performance evidence can be reviewed jointly. South African experience also demonstrates that pricing, governance and stakeholder confidence are closely connected, reinforcing the need for transparent institutional arrangements that align port investment with national logistics priorities (Gumede and Chasomeris, 2015).

Financial constraints affect both initial implementation and long-term system sustainability. Sensors, servers, communication networks, cybersecurity controls, software licences and specialist personnel require recurrent funding, not merely capital expenditure. Digital transformation can also demand changes in organisational processes and value creation models, making leadership commitment and strategic alignment essential (Rachinger et al., 2019). Ports should therefore adopt modular systems, prioritise high-impact operational problems and evaluate benefits against baselines such as vessel waiting time, cargo dwell time, equipment availability and gate congestion. Partnerships with technology providers, development institutions and research organisations may reduce capability gaps, although procurement must preserve data ownership, interoperability and local maintenance capacity.

User acceptance and workforce competence are equally decisive. Systems that are difficult to use, poorly explained or perceived as instruments of surveillance may be bypassed through informal practices. Venkatesh et al. (2003) identify performance expectancy, effort expectancy, social influence and facilitating conditions as central determinants of technology use. Port implementation programmes should therefore combine technical training with role redesign, managerial support, user consultation and incentives linked to accurate data entry and evidence-based decisions. Future research should examine how organisational culture, labour relations and professional identity influence adoption across different port governance environments.

Infrastructure resilience is another enabling condition. Monitoring platforms depend on continuous electricity for data centres, sensors, smart gates, communications and control rooms. Nigerian evidence indicates that solar-power integration can improve operational resilience where grid electricity is unreliable (Sunday and Omoegun, 2018). Hybrid systems also require effective load allocation so that essential digital and operational equipment receives priority during constrained supply (Sunday and Omoegun, 2019). Port research should therefore examine relationships among energy reliability, system availability, data loss and decision-response time, while testing renewable-energy configurations under actual terminal conditions.

Cybersecurity, privacy and innovation governance require sustained attention as port systems become increasingly interconnected. Digital platforms may expose commercially sensitive information and critical infrastructure to unauthorised access, manipulation or disruption. Successful innovation requires organisational commitment, stakeholder participation and supportive regulatory conditions rather than technology alone (Acciaro et al., 2014). Future studies should develop context-specific digital-maturity models, compare implementation pathways across African, Asian and Latin American ports, and test predictive analytics using longitudinal operational data. Research should also evaluate affordability, model transparency, cybersecurity readiness, environmental effects and the distribution of digitalisation benefits among port stakeholders. Pilot projects should also test scalability before commitments to port-wide deployment.

VIII. CONCLUSION

This review has fulfilled its central aim by developing a coherent framework for applying data-driven performance monitoring to improve operational efficiency in developing-economy ports. It achieved this by examining the operational structure of maritime logistics, identifying major sources of inefficiency, evaluating relevant performance indicators, assessing enabling digital technologies, and integrating these elements into a context-sensitive monitoring architecture. The analysis established that persistent challenges such as vessel congestion, excessive cargo dwell time, equipment downtime, fragmented documentation, weak hinterland connectivity, unreliable electricity, and institutional silos are intensified by inadequate data quality and limited real-time visibility.

The study further demonstrated that effective monitoring depends on more than technological acquisition. Sustainable improvement requires strategic alignment, standardised indicators, interoperable systems, reliable infrastructure, skilled personnel, strong governance, stakeholder coordination, and mechanisms that convert analytical insights into timely operational action. Key findings indicate that balanced performance measurement should combine vessel, berth, cargo, yard, gate, customs, service-quality, safety, environmental, and connectivity indicators. The review also confirmed that descriptive, diagnostic, predictive, and prescriptive analytics can strengthen planning, early warning, resource allocation, accountability, and continuous improvement when supported by dependable data.

Accordingly, developing-economy ports should adopt a phased implementation pathway. Initial efforts should prioritise data governance, process mapping, resilient power supply, essential performance indicators, and staff capability development. Subsequent stages should integrate port community systems, automated data acquisition, role-specific dashboards, predictive models, and cross-agency decision protocols. Policymakers should support regulatory reform, cybersecurity standards, public-private investment, and regional knowledge exchange. Port authorities should also undertake periodic framework evaluation using measurable operational outcomes. Overall, the evidence supports data-driven monitoring as a practical governance and management instrument capable of improving reliability, reducing inefficiency, strengthening competitiveness, and supporting more resilient maritime logistics systems. Its effectiveness, however, will depend on disciplined implementation, institutional commitment, sustained investment, transparent evaluation, and adaptation to evolving local operational realities.

REFERENCES

[1] Bichou, K. and Gray, R. (2004) ‘A logistics and supply chain management approach to port performance measurement’, Maritime Policy & Management, 31(1), pp. 47–67. DOI: 10.1080/0308883032000174454.

[2] Carlo, H.J., Vis, I.F.A. and Roodbergen, K.J. (2014) ‘Transport operations in container terminals: Literature overview, trends, research directions and classification scheme’, European Journal of Operational Research, 236(1), pp. 1–13. DOI: 10.1016/j.ejor.2013.11.023.

[3] Heilig, L. and Voß, S. (2017) ‘Information systems in seaports: A categorization and overview’, Information Technology and Management, 18(3), pp. 179–201. DOI: 10.1007/s10799-016-0269-1.

[4] Inkinen, T., Helminen, R. and Saarikoski, J. (2019) ‘Port digitalization with open data: Challenges, opportunities, and integrations’, Journal of Open Innovation: Technology, Market, and Complexity, 5(2), article 30. DOI: 10.3390/joitmc5020030.

[5] Merkel, A. and Holmgren, J. (2017) ‘Dredging the depths of knowledge: Efficiency analysis in the maritime port sector’, Transport Policy, 60, pp. 63–74. DOI: 10.1016/j.tranpol.2017.08.010.

[6] Sánchez, R.J., Hoffmann, J., Micco, A., Pizzolitto, G.V., Sgut, M. and Wilmsmeier, G. (2003) ‘Port efficiency and international trade: Port efficiency as a determinant of maritime transport costs’, Maritime Economics & Logistics, 5(2), pp. 199–218. DOI: 10.1057/palgrave.mel.9100073.

[7] Suárez-Alemán, A., Morales Sarriera, J., Serebrisky, T. and Trujillo, L. (2016) ‘When it comes to container port efficiency, are all developing regions equal?’, Transportation Research Part A: Policy and Practice, 86, pp. 56–77. DOI: 10.1016/j.tra.2016.01.018.

[8] Trujillo, L., González, M.M. and Jiménez, J.L. (2013) ‘An overview on the reform process of African ports’, Utilities Policy, 25, pp. 12–22. DOI: 10.1016/j.jup.2013.01.002.

[9] Ugboma, C., Ogwude, I.C., Ugboma, O. and Nnadi, K. (2007) ‘Service quality and satisfaction measurements in Nigerian ports: An exploration’, Maritime Policy & Management, 34(4), pp. 331–346. DOI: 10.1080/03088830701539073.

[10] Yuen, C.-L.A., Zhang, A. and Cheung, W. (2012) ‘Port competitiveness from the users’

perspective: An analysis of major container ports in China and its neighbouring countries', Research in Transportation Economics, 35(1), pp. 34–40. DOI: 10.1016/j.retrec.2011.11.005.

References

[11] Bichou, K. and Gray, R. (2004) 'A logistics and supply chain management approach to port performance measurement', Maritime Policy & Management, 31(1), pp. 47–67. DOI: 10.1080/0308883032000174454.
[12] Carlo, H.J., Vis, I.F.A. and Roodbergen, K.J. (2014) 'Transport operations in container terminals: Literature overview, trends, research directions and classification scheme', European Journal of Operational Research, 236(1), pp. 1–13. DOI: 10.1016/j.ejor.2013.11.023.
[13] Clark, X., Dollar, D. and Micco, A. (2004) 'Port efficiency, maritime transport costs, and bilateral trade', Journal of Development Economics, 75(2), pp. 417–450. DOI: 10.1016/j.jdeveco.2004.06.005.
[14] Cullinane, K., Wang, T.F., Song, D.W. and Ji, P. (2006) 'The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis', Transportation Research Part A: Policy and Practice, 40(4), pp. 354–374. DOI: 10.1016/j.tra.2005.07.003.
[15] Heilig, L. and Voß, S. (2017) 'Information systems in seaports: A categorization and overview', Information Technology and Management, 18(3), pp. 179–201. DOI: 10.1007/s10799-016-0269-1.
[16] Kammoun, R. (2018) 'The technical efficiency of Tunisian ports: Comparing data envelopment analysis and stochastic frontier analysis scores', Logistics & Sustainable Transport, 9(2), pp. 73–84. DOI: 10.2478/jlst-2018-0011.
[17] Notteboom, T.E. (2006) 'The time factor in liner shipping services', Maritime Economics & Logistics, 8(1), pp. 19–39. DOI: 10.1057/palgrave.mel.9100148.
[18] Suárez-Alemán, A., Morales Sarriera, J., Serebrisky, T. and Trujillo, L. (2016) 'When it comes to container port efficiency, are all developing regions equal?', Transportation Research Part A: Policy and Practice, 86, pp. 56–77. DOI: 10.1016/j.tra.2016.01.018.
[19] Trujillo, L., González, M.M. and Jiménez, J.L. (2013) 'An overview on the reform process of African ports', Utilities Policy, 25, pp. 12–22. DOI: 10.1016/j.jup.2013.01.002.
[20] Ugboma, C., Ogwude, I.C., Ugboma, O. and Nnadi, K. (2007) 'Service quality and satisfaction measurements in Nigerian ports: An exploration', Maritime Policy & Management, 34(4), pp. 331–346. DOI: 10.1080/03088830701539073.
[21] Fruth, M. and Teuteberg, F. (2017) 'Digitization in maritime logistics: What is there and what is missing?', Cogent Business & Management, 4(1), article 1411066. DOI: 10.1080/23311975.2017.1411066.
[22] Gunasekaran, A., Papadopoulos, T., Dubey, R., Wamba, S.F., Childe, S.J., Hazen, B. and Akter, S. (2017) 'Big data and predictive analytics for supply chain and organizational performance', Journal of Business Research, 70, pp. 308–317. DOI: 10.1016/j.jbusres.2016.08.004.
[23] Hazen, B.T., Boone, C.A., Ezell, J.D. and Jones-Farmer, L.A. (2014) 'Data quality for data science, predictive analytics, and big data in supply chain management: An introduction to the problem and suggestions for research and applications', International Journal of Production Economics, 154, pp. 72–80. DOI: 10.1016/j.ijpe.2014.04.018.
[24] Heilig, L. and Voß, S. (2017) 'Information systems in seaports: A categorization and overview', Information Technology and Management, 18(3), pp. 179–201. DOI: 10.1007/s10799-016-0269-1.
[25] Hofmann, W. and Branding, F. (2019) 'Implementation of an IoT- and cloud-based digital twin for real-time decision support in port operations', IFAC-PapersOnLine, 52(13), pp. 2104–2109. DOI: 10.1016/j.ifacol.2019.11.516.
[26] Inkinen, T., Helminen, R. and Saarikoski, J. (2019) 'Port digitalization with open data: Challenges, opportunities, and integrations', Journal of Open Innovation: Technology, Market, and Complexity, 5(2), article 30. DOI: 10.3390/joitmc5020030.
[27] Kache, F. and Seuring, S. (2017) 'Challenges and opportunities of digital information at the intersection of big data analytics and supply chain management', International Journal of Operations & Production Management, 37(1), pp. 10–36. DOI: 10.1108/IJOPM-02-2015-0078.

[28] Kammoun, R. (2018) 'The technical efficiency of Tunisian ports: Comparing data envelopment analysis and stochastic frontier analysis scores', Logistics & Sustainable Transport, 9(2), pp. 73–84. DOI: 10.2478/jlst-2018-0011.

[29] Ugboma, C., Ogwude, I.C., Ugboma, O. and Nnadi, K. (2007) 'Service quality and satisfaction measurements in Nigerian ports: An exploration', Maritime Policy & Management, 34(4), pp. 331–346. DOI: 10.1080/03088830701539073.

[30] Waller, M.A. and Fawcett, S.E. (2013) 'Data science, predictive analytics, and big data: A revolution that will transform supply chain design and management', Journal of Business Logistics, 34(2), pp. 77–84. DOI: 10.1111/jbl.12010.

References

[31] Bichou, K. and Gray, R. (2004) 'A logistics and supply chain management approach to port performance measurement', Maritime Policy & Management, 31(1), pp. 47–67. DOI: 10.1080/0308883032000174454.

[32] Cullinane, K., Wang, T.F., Song, D.W. and Ji, P. (2006) 'The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis', Transportation Research Part A: Policy and Practice, 40(4), pp. 354–374. DOI: 10.1016/j.tra.2005.07.003.

[33] Ha, M.H., Yang, Z., Notteboom, T., Ng, A.K.Y. and Heo, M.W. (2017) 'Revisiting port performance measurement: A hybrid multi-stakeholder framework for the modelling of port performance indicators', Transportation Research Part E: Logistics and Transportation Review, 103, pp. 1–16. DOI: 10.1016/j.tre.2017.04.008.

[34] Kammoun, R. (2018) 'The technical efficiency of Tunisian ports: Comparing data envelopment analysis and stochastic frontier analysis scores', Logistics & Sustainable Transport, 9(2), pp. 73–84. DOI: 10.2478/jlst-2018-0011.

[35] Lim, S., Pettit, S., Abouarghoub, W. and Beresford, A. (2019) 'Port sustainability and performance: A systematic literature review', Transportation Research Part D: Transport and Environment, 72, pp. 47–64. DOI: 10.1016/j.trd.2019.04.009.

[36] Munim, Z.H. and Schramm, H.J. (2018) 'The impacts of port infrastructure and logistics performance on economic growth: The mediating role of seaborne trade', Journal of Shipping and Trade, 3(1), article 1, pp. 1–19. DOI: 10.1186/s41072-018-0027-0.

[37] Notteboom, T.E. (2006) 'The time factor in liner shipping services', Maritime Economics & Logistics, 8(1), pp. 19–39. DOI: 10.1057/palgrave.mel.9100148.

[38] Suárez-Alemán, A., Morales Sarriera, J., Serebrisky, T. and Trujillo, L. (2016) 'When it comes to container port efficiency, are all developing regions equal?', Transportation Research Part A: Policy and Practice, 86, pp. 56–77. DOI: 10.1016/j.tra.2016.01.018.

[39] Ugboma, C., Ogwude, I.C., Ugboma, O. and Nnadi, K. (2007) 'Service quality and satisfaction measurements in Nigerian ports: An exploration', Maritime Policy & Management, 34(4), pp. 331–346. DOI: 10.1080/03088830701539073.

[40] Yuen, C.L.A., Zhang, A. and Cheung, W. (2012) 'Port competitiveness from the users' perspective: An analysis of major container ports in China and its neighbouring countries', Research in Transportation Economics, 35(1), pp. 34–40. DOI: 10.1016/j.retrec.2011.11.005.

References

[41] Carlan, V., Sys, C. and Vanelslander, T. (2016) 'How port community systems can contribute to port competitiveness: Developing a cost–benefit framework', Research in Transportation Business & Management, 19, pp. 51–64. DOI: 10.1016/j.rtbm.2016.03.009.

[42] Carlan, V., Sys, C., Vanelslander, T. and Roumboutsos, A. (2017) 'Digital innovation in the port sector: Barriers and facilitators', Competition and Regulation in Network Industries, 18(1–2), pp. 71–93. DOI: 10.1177/1783591717734793.

[43] Harati-Mokhtari, A., Wall, A., Brooks, P. and Wang, J. (2007) 'Automatic Identification System (AIS): Data reliability and human error implications', The Journal of Navigation, 60(3), pp. 373–389. DOI: 10.1017/S0373463307004298.

[44] Kia, M., Shayan, E. and Ghotb, F. (2000) 'The importance of information technology in port terminal operations', International Journal of Physical Distribution & Logistics Management,

30(3/4), pp. 331–344. DOI: 10.1108/09600030010326118.

[45] Mlimbila, J. and Mbamba, U.O.L. (2018) 'The role of information systems usage in enhancing port logistics performance: Evidence from the Dar es Salaam port, Tanzania', Journal of Shipping and Trade, 3, article 10, pp. 1–20. DOI: 10.1186/s41072-018-0036-z.

[46] Ngai, E.W.T., Li, C.L., Cheng, T.C.E., Lun, Y.H.V., Lai, K.H., Cao, J. and Lee, M.C.M. (2011) 'Design and development of an intelligent context-aware decision support system for real-time monitoring of container terminal operations', International Journal of Production Research, 49(12), pp. 3501–3526. DOI: 10.1080/00207541003801291.

[47] Oyedepo, S.O. (2012) 'Energy and sustainable development in Nigeria: The way forward', Energy, Sustainability and Society, 2, article 15. DOI: 10.1186/2192-0567-2-15.

[48] Tijan, E., Aksentijević, S., Ivanić, K. and Jardas, M. (2019) 'Blockchain technology implementation in logistics', Sustainability, 11(4), article 1185. DOI: 10.3390/su11041185.

[49] Tsamboulas, D., Moraiti, P. and Lekka, A.M. (2012) 'Performance evaluation for implementation of port community system', Transportation Research Record: Journal of the Transportation Research Board, 2273(1), pp. 29–37. DOI: 10.3141/2273-04.

[50] Zerbino, P., Aloini, D., Dulmin, R. and Mininno, V. (2019) 'Towards analytics-enabled efficiency improvements in maritime transportation: A case study in a Mediterranean port', Sustainability, 11(16), article 4473. DOI: 10.3390/su11164473.

References

[51] Barros, C.P. (2012) 'Productivity assessment of African seaports', African Development Review, 24(1), pp. 67–78. DOI: 10.1111/j.1467-8268.2011.00305.x.

[52] DeLone, W.H. and McLean, E.R. (2003) 'The DeLone and McLean model of information systems success: A ten-year update', Journal of Management Information Systems, 19(4), pp. 9–30. DOI: 10.1080/07421222.2003.11045748.

[53] Ferreira, A. and Otley, D. (2009) 'The design and use of performance management systems: An extended framework for analysis', Management Accounting Research, 20(4), pp. 263–282. DOI: 10.1016/j.mar.2009.07.003.

[54] Neely, A., Gregory, M. and Platts, K. (1995) 'Performance measurement system design: A literature review and research agenda', International Journal of Operations & Production Management, 15(4), pp. 80–116. DOI: 10.1108/01443579510083622.

[55] Notteboom, T.E. and Rodrigue, J.P. (2005) 'Port regionalization: Towards a new phase in port development', Maritime Policy & Management, 32(3), pp. 297–313. DOI: 10.1080/03088830500139885.

[56] Ojadi, F.I. and Walters, J. (2015) 'Critical factors that impact on the efficiency of the Lagos seaports', Journal of Transport and Supply Chain Management, 9(1), article 180, pp. 1–13. DOI: 10.4102/jtscm.v9i1.180.

[57] Panayides, P.M. and Song, D.W. (2009) 'Port integration in global supply chains: Measures and implications for maritime logistics', International Journal of Logistics Research and Applications, 12(2), pp. 133–145. DOI: 10.1080/13675560902749407.

[58] Popovič, A., Hackney, R., Coelho, P.S. and Jaklič, J. (2012) 'Towards business intelligence systems success: Effects of maturity and culture on analytical decision making', Decision Support Systems, 54(1), pp. 729–739. DOI: 10.1016/j.dss.2012.08.017.

[59] Sunday, E.A. and Omoegun, G.O. (2018) 'Integrating solar power solutions in small-scale manufacturing industries in Nigeria', International Journal of Scientific Research in Science, Engineering and Technology, 4(8), pp. 832–853.

[60] Sunday, E.A. and Omoegun, G.O. (2019) 'Optimizing electrical load distribution for hybrid solar installations in developing economies', International Journal of Scientific Research in Mechanical and Materials Engineering, 3(6), pp. 27–47.

References

[61] Acciaro, M., Vanelslander, T., Sys, C., Ferrari, C., Roumboutsos, A., Giuliano, G., Lam, J.S.L. and Kapros, S. (2014) 'Environmental sustainability in seaports: A framework for successful innovation', Maritime Policy & Management, 41(5), pp. 480–500. DOI: 10.1080/03088839.2014.932926.

[62] Brooks, M.R. and Pallis, A.A. (2008) ‘Assessing port governance models: Process and performance components’, Maritime Policy & Management, 35(4), pp. 411–432. DOI: 10.1080/03088830802215060.

[63] de Langen, P.W. (2006) ‘Stakeholders, conflicting interests and governance in port clusters’, Research in Transportation Economics, 17, pp. 457–477. DOI: 10.1016/S0739-8859(06)17020-1.

[64] Gumede, S. and Chasomeris, M. (2015) ‘Maritime port pricing and governance in South Africa: Trends and stakeholder comments’, Journal of Economic and Financial Sciences, 8(1), article 83. DOI: 10.4102/jef.v8i1.83.

[65] Ng, A.K.Y. and Pallis, A.A. (2010) ‘Port governance reforms in diversified institutional frameworks: Generic solutions, implementation asymmetries’, Environment and Planning A, 42(9), pp. 2147–2167. DOI: 10.1068/a42514.

[66] Notteboom, T.E., de Langen, P.W. and Jacobs, W. (2013) ‘Institutional plasticity and path dependence in seaports: Interactions between institutions, port governance reforms and port authority routines’, Journal of Transport Geography, 27, pp. 26–35. DOI: 10.1016/j.jtrangeo.2012.05.002.

[67] Rachinger, M., Rauter, R., Müller, C., Vorraber, W. and Schirgi, E. (2019) ‘Digitalization and its influence on business model innovation’, Journal of Manufacturing Technology Management, 30(8), pp. 1143–1160. DOI: 10.1108/JMTM-01-2018-0020.

[68] Sunday, E.A. and Omoegun, G.O. (2018) ‘Integrating solar power solutions in small-scale manufacturing industries in Nigeria’, International Journal of Scientific Research in Science, Engineering and Technology, 4(8), pp. 832–853. No verifiable standard DOI located. Publisher record.

[69] Sunday, E.A. and Omoegun, G.O. (2019) ‘Optimizing electrical load distribution for hybrid solar installations in developing economies’, International Journal of Scientific Research in Mechanical and Materials Engineering, 3(6), pp. 27–47. No verifiable standard DOI located. Publisher record.

[70] Venkatesh, V., Morris, M.G., Davis, G.B. and Davis, F.D. (2003) ‘User acceptance of information technology: Toward a unified view’, MIS Quarterly, 27(3), pp. 425–478. DOI: 10.2307/30036540.