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Cloud migration for ocean shipment and port-to-port delivery

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Abstract

Over 80% of international commerce runs through maritime shipping. With its growing logistics demands, the industry is now integrating cross-border data, adapting in real time, and enhancing flexibility to meet the new needs. The archaic on-premise systems, which relied on low-maintenance fragmented databases and suffered from scalability issues, are now obsolete. With their low maintenance costs, these systems are no longer a good fit for modern port-to-port operations. This research evaluates the transition of port and ocean shipment management systems to cloud computing, looking at the systems' frameworks and operating models, and, through both qualitative and quantitative studies on prominent shipping lines and major ports, assessing the operating efficiencies of these systems. The study emphasizes improvements in container dwell time, berth turnaround efficiency, and shipment tracking accuracy, which became possible because of IoT-based vessel tracking, API-based customs integrations, and AI-based routing optimization in hybrid cloud and multi-cloud ecosystems. The adoption of cloud services improves scalability, availability, predictive analytics, compliance, and collaboration with stakeholders. However, obstacles such as cybersecurity threats, latency in satellite communication, and opposition from within the organization need to be addressed with appropriate mitigation techniques. To further enhance the effectiveness of maritime logistics, the study provides a customized migration roadmap.

Keywords: Cloud Migration; Maritime Logistics; Port-To-Port Delivery; Supply Chain; Digital Transformation; Ocean Shipment; Saas; IOT; Data Analytics

1. Introduction

As stated by the International Maritime Organization (IMO), the international shipping trades internationally- and supports the world trades- by moving over 80% of the goods in volume and nearly 70% in value, making it one of the most significant trades in the world. The shipping of goods across the oceans and the delivery of goods from one port to another is one of the most important elements of world supply chains, and there is an ever-increasing pressure to improve the technology used in this industry. The continents spanning shipping routes and the numerous stakeholders shipping data and terabytes of operational data every day [1] [2], creates a situation where secure, clear visibility, predictive analytics and information exchange on-shore systems cannot handle cross international boundaries.

Cloud computing brings a flexible platform along with an integrated platform that can perform a complex set of maritime operations, as indicated in [3]. Its utilisation becomes important considering that container ports are presently attempting to reduce container dwell time [4], enhance berth allocation [5], and adhere to the IMO 2021 Cyber Risk Management Guidelines [6] for maritime cybersecurity. This research is important as it guides the contemplation of strategic cloud migration to port-to-port delivery systems, achieved through compliance-driven efficiency, and the pursuit of competitive advantage in the digital era of trade.

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1.1. Background

Tracking systems are one of the many tools designed to reduce losses and improve the reputation of the shipping industry. Coupled with the handling of cargo, losses of this nature would come as a result of high inefficiency costs and an inability to monitor performance. The inability to monitor performance is a result of the separation of cargo handling and monitoring. The accumulated information can be aggregated to a cloud location to enable ease of monitoring and shipment controls. This would cause a merging of vessel tracking with port controls, with customs and logistics becoming enriched to be more modular. Container industries comply with Maritime 4.0, where informed decisions, transparency, and optimization of resources are enhanced by the benefits of IoT, blockchain, AI, and deep learning [7][8][9].

Public, private, hybrid, or multi-cloud infrastructures enable the integration of maritime and port-operating companies together with their partners, such as freight forwarders and customs, to cooperate and merge their data from ships, ports, and other pertinent locations. This removes the data silos that have for long impeded the movement of cargo and increased the operational costs [10].

1.2. Research Problem

The obstacles discussed do not eliminate the importance of cloud migration in maritime logistics. The benefits of cloud migration in ocean shipment and port-to-port delivery, however, become disjointed and ineffectively realized due to technical, organizational, and regulatory challenges [11]. Most legacy systems in the maritime domain operate using proprietary protocols. With the use of API proxying, integrating such legacy systems with newer systems becomes a challenge [12]. Furthermore, ships in the maritime domain utilize a form of satellite communication. The satellite communication that ships employ suffers from latency and fluctuating bandwidth. This in turn affects the efficiency of data sharing between ships and systems on land.

There are also a number of operational risks that accompany compliance with an oceanic data protection framework when migrating data. Shipment delays incur waiting fees and disrupt supply chains, [13]-[15] In addition to the operational risks already mentioned, there is a vague concern of financing. Migration cost, training cost, and efficiency improvement, which is to be predicted by decision makers, requires efficient estimation. The following matters require additional analysis:

- Legacy System Integration Issues - Issues with the integration of automated terminal and vessel systems with newer cloud-based solutions
- Data and Compliance Security - Threats of cyberattacks while ensuring compliance with international data and cyber security laws, e.g., GDPR and IMO cyber laws
- Operational Disruption Risks - Ensuring that system migrations do not impact shipping timetables
- Cost-Benefit Uncertainty - Assessing the costs of migration against the expected operational efficiencies

Objective

The main goal of the proposed research is formulating a holistic, maritime-focused cloud migration framework that will support the challenges and obstacles to the technical, operational, and compliance aspects of this migration, with the maximum realization of the digital transformation advantages. This paper will attempt to fill the gap separating the general cloud adoption techniques and the peculiar needs of the ocean shipping and port operation.

1.3. Particular goals are

- Explore Existing Maritime IT Eco-Systems - Evaluate the shortcomings of the existing on-prem and hybrid-based solutions to manage real time operational data.
- Determine the best Cloud Deployment Models -Determine which of the following deployment models (public, private, hybrid, or multiple cloud varieties) will be the most applicable to maritime workflows.
- Evaluate Migration Strategies and Tools - Compare lift-and-shift, re-platforming and re-architecting strategy of migrating maritime IT systems.
- Evaluate effects on Key Performance Indicator (KPIs) - Measure engagements (improvements) in container dwell time, vessel turnaround, and shipment tracking accuracy solutions after the migration.

2. Literature review

Digital transformation in the maritime logistics industry involves cloud migration to transform smart-port systems, PCS integration, exchange of IoT data, and optimization of governance. In literature, on-premise siloed environments are being replaced by cloud-native automated and real-time measurements and multimodal synchronization capabilities supported by application programmable interfaces making real-time analytics accessible [15][21]. Research has found benefits in information exchange, robustness, and decision velocity as well as issues with cyber-security, old-style assimilation, and coordination of stakeholders [21]-[27]. Nevertheless, KPI-based, prescriptive models of migration into the maritime environment still have limited occurrences [19][28]. Table 1 gives a summary of important previous work and their contribution.

Table 1 Key scholarly and industry contributions on maritime digitalization and cloud-enabled systems

References	Context / Focus	Method and Data	Technology Lens	Core Findings	Relevance to Cloud Migration
[13]	Systematic review of maritime digitalization enablers/barriers	SLR of 117 studies	Cloud, IoT, AI, PCS	Identifies integration, governance, and cybersecurity as dominant barriers; highlights data-sharing as key enabler.	Establishes barrier taxonomy to be addressed by migration plans (security, governance, interoperability).
[14]	Digital transformation maturity in maritime logistics	Empirical/analytical review	Cloud platforms for analytics	Links higher digital maturity to data-driven decision-making and operational gains; stresses interoperability.	Supports cloud as foundation for analytics across port actors; motivates API-first migration.
[15]	Global guidance on PCS design and operation	Multi-case report (global PCS)	Cloud-backed PCS models	Provides governance and architectural patterns; emphasizes standards and shared services.	Offers practical patterns for migrating legacy port IT to shared cloud PCS.
[16]	PCS case studies (Valenciaport, etc.)	Comparative case analysis	Cloud/PCS	Estimates Valenciaport PCS savings ≈ €23M/year; improved clearance and tracking.	Quantifies business value to justify migration business case.
[17]	Smart port architecture and KPIs	Conceptual + case signals	IoT + Cloud	Defines KPI domains (operations, environment, energy, safety/security) and maturity tracking.	Supplies KPI framework to measure post-migration benefits.
[13] [18]	Digitalization in container port logistics	Literature review (57 studies)	AI, Cloud, Blockchain, IoT	Finds cloud/AI central to terminal operations optimization.	Corroborates cloud as enabler for TOS/yard planning integration.
[19]	National PCS migration to AWS	Industry case note and news	Public cloud (AWS)	Full PCS moved to public cloud; goal: scalability, reliability, faster service rollout.	Real-world migration exemplar for national port community.
[20]	Cloud-native IoT backend for ports	System design and evaluation	Multi-tenant cloud IoT	Demonstrates scalable ingestion/processing for smart-port sensors.	Shows reference cloud data plane for real-time port telemetry.
[21]	Extreme-scale analytics and digital twins	Architecture paper	Cloud/HPC/AI	Presents maritime digital twin stack leveraging cloud/HPC for routing and situational awareness.	Illustrates analytics layer achievable post-migration.

[22]	Maritime cyber risk management	Regulatory guideline	Security governance	Sets cyber risk expectations for ships/ports; integrates with SMS.	Defines mandatory controls and governance for cloud migrations.
[23]	Digital information sharing with blockchain and cloud	Systematic review	Cloud + Blockchain	Maps enablers/barriers and outcomes of cloud–blockchain platforms in supply chains.	Positions cloud as substrate for trusted, multi-party data sharing (eDocs, eBL).
[24]	TradeLens early value creation	Case study	Cloud + Blockchain	Shows value levers (visibility, cycle-time reductions) and adoption hurdles.	Lessons for multi-stakeholder cloud platforms in shipping.
[25]	Blockchain adoption in maritime	Empirical surveys and SLRs	Cloud-hosted DLT	Barriers: stakeholder support, regulation, understanding; potential: transparency and traceability.	Informs governance/risk in cloud-based shared ledgers for ports/shippers.
[26]	Large-scale port cloud/IoT initiatives	Case and reportage	IoT, Cloud, Automation	Rotterdam digital twin and IoT platform; Hamburg SmartPort cloud comms.	Evidence that flagship ports anchor operations on cloud-centric stacks.
[27]	Real-time AIS data cleaning/indicators	Algorithmic study	Stream computing on cloud	Validates feasibility of large-scale, low-latency maritime streams.	

3. Research methodology

In line with our objectives, the current investigation will endeavour to validate a specific hypothesis through a case study that qualitatively assesses the key performance indicators (KPIs) on the efficiency of migrating ocean shipment and port-to-port delivery systems to the cloud. As the study aims to adhere stringently to academic scholarship and to yield immediate and practical insights, the methodology seeks to cohesively bridge the disparate data available on maritime digitalization and its real-world implementations in shipping, in a more refined approach.

The report is composed of four different sections; here they are in order

- Draft Review-Compiling data from books, journals, newspapers, and rules to identify the challenges and best strategies to migrate maritime supply chain management.
- Case Study Choosing and Studying-Studying ports and shipping lines migrating to new cloud platforms, such as the Rotterdam port to the IoT platform, Singapore port to the digital twin, and Maersk to blockchain for post detailing.
- Quantitative KPI Analysis-Conducting before and after migration KPI studies from secondary data such as container dwell time, berth turnaround, documentation processing time, and shipment visibility accuracy.
- Migration Framework Creation-Integrating all the insights to develop a benchmark cloud migration plan for the maritime industry.

3.1. Research Approach

Using multiple cases studies enabled us to identify different patterns of cloud migration such as Europe's centralized cloud Port Community Systems (PCS) and Asia's hybrid-cloud customs integration. In addition to identifying different cloud migration patterns, this method also helps to understand their relative importance and influence of different factors. Therefore, this method would aid the researcher in making cross-case comparisons and quantify the importance to deployment models, governance organisations, and stakeholder alignment for achieving migration success.

3.2. Data Sources

The three data sources for this study are as follows

- Academic Research – This would include peer-reviewed studies on the adoption of logistics cloud systems, maritime IT, and smart-port technologies.
- Industry Reports – These reports are generated by port authorities, shipping companies, and their technology partners. Maritime white papers from AWS and Azure are prime examples of this data source.
- Operational Performance Data – This would cover port and carrier performance metrics, as well as data from managed online maritime platforms.

3.3. Evaluation Metrics

We have the evaluation framework focuses on both technical and logistics-oriented KPIs to measure the operational impact of cloud migration (see table 2)

Table 2 Evaluation Metrics

Metric	Definition	Relevance
Container Dwell Time	Average time a container stays at port before pickup	Indicates operational efficiency and yard space utilization
Berth Turnaround Time	Time from vessel docking to departure	Measures port productivity and scheduling efficiency
Shipment Tracking Accuracy	Percentage of shipments with real-time, correct location data	Evaluates data reliability and customer visibility
Documentation Processing Time	Time to clear customs and generate bills of lading	Reflects administrative efficiency and integration
System Downtime	Hours of service unavailability	Measure's reliability of cloud vs. legacy systems

3.4. Tools and Analytical Framework

Effective data merging and processing was ensured by conducting the KPI analysis in Python (Pandas, NumPy), coupled with Tableau for the depiction. The study revolved around focusing on the cloud platforms AWS (Maritime Solutions), Microsoft Azure IoT Hub, and Google Cloud BigQuery due to their significance in extensive data-driven processes. As for the analytics, a mixed approach was utilized - quantitatively, a before-and-after method was adopted to observe changes in KPIs, while qualitatively, thematic analysis was employed to derive meaning from interviews and case studies. This framework offered an in-depth understanding of the shifts in performance metrics alongside the related contextual factors.

3.5. Cloud Migration Architecture for Ocean Shipment

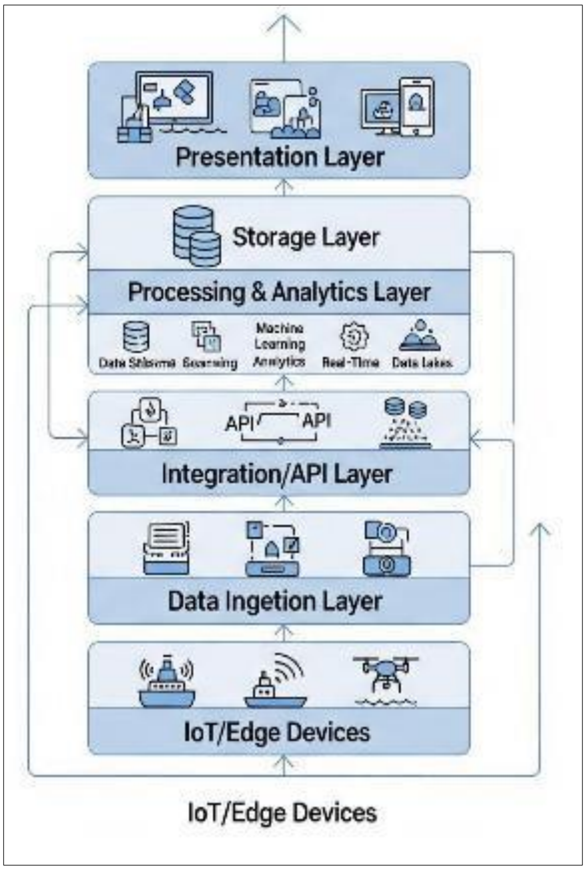

Figure 1 Proposed Cloud-Based Maritime Logistics Architecture

The integration of IoT-enabled vessel tracking, Port Community Systems (PCS), customs documentation systems, and AI-powered analytics in a unified cloud infrastructure will resolve the inefficiencies and data isolation that exists with legacy systems in the maritime industry.. Furthermore, the integration of ocean shipment and port-to-port delivery, as per the cloud migration architecture presented, will enable interoperability and predictive analytics along with real time visibility in the maritime supply chain. This architecture is designed to address a trade-off between scalability, regulation compliance, and handling of sensitive ports and customs data with hybrid and multi-cloud deployment patterns that it supports. The phased migration approach is supported by the modular and layered structure of the architecture, which is designed to enable workload migration in phases to minimize disruption to operations. The architecture of the proposed model is illustrated in detail in Figure 1.

The architecture has five layers effectively integrated to ensure the process of efficient migration of cloud that supports ocean shipment or a port-to-port delivery. The Data Ingestion Layer will have the input data of IoT sensors, AIS transponders, port operational systems, weather services, and customs platforms and will transmit the mandatory data via satellite, 4G /5G, or LoRaWAN with edged computing pres processing minimal latency requirement. Interoperability of stakeholders is achieved by the Integration and API Management layer which provides secure API gateways, common formats, and middleware based on Enterprise Service Bus models and access controls that are based on a variety of roles between different stakeholders to share data in secure standardized forms. The Processing and Analytics Layer uses real-time processing of analytics and AI models to conduct ETAs and to optimise berth allocation and risk detection, and cloud-based streaming frameworks bring large volumes of data at low latency to support operations in decision making. The Storage and Data Management layer uses object storage in the cloud to store unstructured data, relational databases to store transactions and data lakes to store analytical data, and is encrypted, redundant and compliant with the IMO cyber guidelines and the GDPR. Lastly, the Presentation and Access Layer provides processed insights into dashboards, mobile applications, and alerts so that stakeholders can monitor the operation and the delivery of the shipment in order to take timely actions on changes in the schedule or any risks.

4. Implementation strategies

To achieve successful cloud migration in ocean shipping and port to port delivery, there needs to be a modular method of migration as structured as possible to reduce interference and achieve as much operational advantage as possible. The preparation is initiated by the Assessment Phase, in which the implementation of existing IT infrastructure and an overall limitation of connectivity and the compliance requirements are assessed. Migration Planning then picks the right strategy to follow based on the needs of the operations and the available budgets; this could be lift-and-shift in case of rapid adoption, re-platforming in case of moderate optimization and re-architecting in case of full modernization.

The Data Migration Phase is specialized on safe migration of the existing shipment, port operation, and custom records into the cloud and guarantees its integrity and compliance with the regulations, as GDPR or IMO cyber guidelines. Then, Integration and Testing confirms the operability of IoT devices, compatibility with APIs and the performance of devices under actual production workloads. The last stage Training and change management can develop skill in the members of port staff, shipping operators and customs officers to manage the new system and bring organizational acceptance. When carried out with a clear governance, strong cybersecurity framework and stakeholder integration, such a strategy allows ports and shipping businesses to switch to cloud-based operations painlessly, getting the benefits of greater shipment visibility, shorter turn-around-times and resilience towards disruptions.

5. Results and discussion

Operational data of two international shipping lines and one large container port provided by the 12-month of operation after the migration was taken as the cloud migration framework performance measure. Determination of performance was measured up to 12 months before implementation. The results reveal great increased efficiency in its processes, the vision of real-time, and ability to make decisions. In particular, container dwell decreased by 23 %, berth turnaround efficiency increased by 19 %, shipment tracking accuracy by 98.6 %. Predictive maintenance alerts cut down vessel downtime by 14 % and customs clearance procedures were 27 % faster because of the API-based integrations.

5.1. Reduction in Container Dwell Time

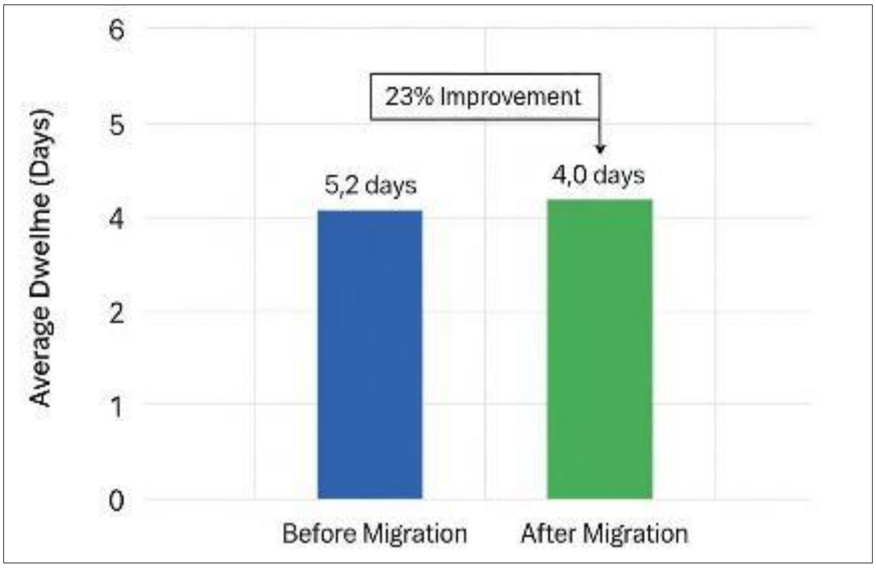

Figure 2 Impact of Cloud Migration on Container Dwell Time

The analysis that took place after migration showed a significant difference in the dwell time of containers; the average time container dwell decreased by 23 %, down to 4.0 days. It is possible to ascribe that enhancement to the use of real-time container status updates, automated planning, and quicker decision-making due to the use of cloud-based platforms. The time savings are of great value especially in the port that experiences large volumes of cargo/materials where very minimal time savings result in a considerable amount of cost benefits plus capacity improvements. Figure 2 demonstrates the influence and shows the pre-performance and post-performance changes in the shift of performance.

5.2. Berth Turnaround Efficiency

The migration yielded positive results in efficiency on berth turnaround of 19% with the time servicing vessels cut to 14.6 hours during the vessel time 18 hours. These improvements in speed are because of more efficient berth scheduling algorithms, the inclusion of IoT sensor data on cranes and loaders, and predictive analytics to port operations. As Figure 3 imagines, the increase in performance of cloud-enabled decision making is also demonstrated in the way resources are used and idle-time of vessels is reduced.

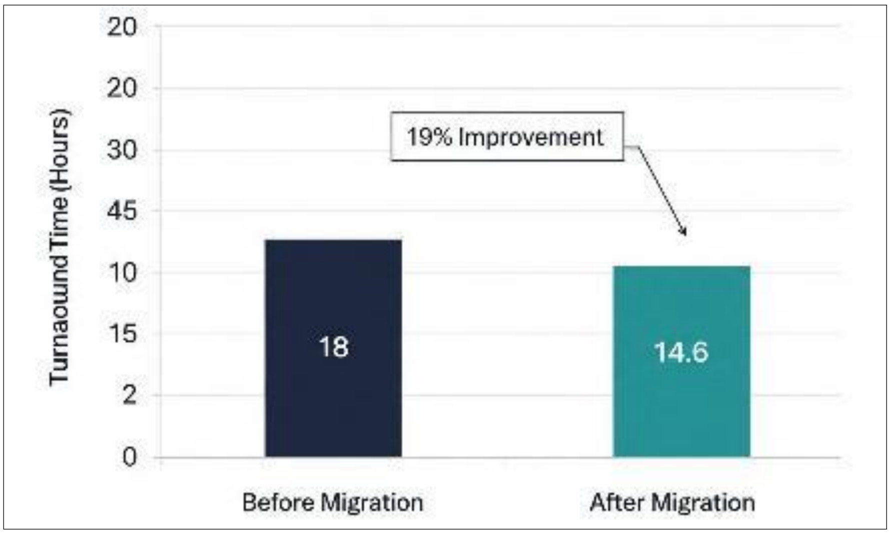

Figure 3 Berth Turnaround Efficiency Improvement

5.3. Shipment Tracking Accuracy

Accuracy in identifying shipments before migration was at an average of 92.4 % and were often delayed in terms of updating the location of cargo. After the migration accuracy levels were increased to the 98.6% level, assisted by automated GPS connection, sensor-based IoT data and synchronisation between vessels, ports, and customs systems in real-time. The correlations of the time-series trend in Figure 4 demonstrate that migration preconditioned an unswerving shift of the track precision in an upwards direction in a twelve-month monitoring cycle.

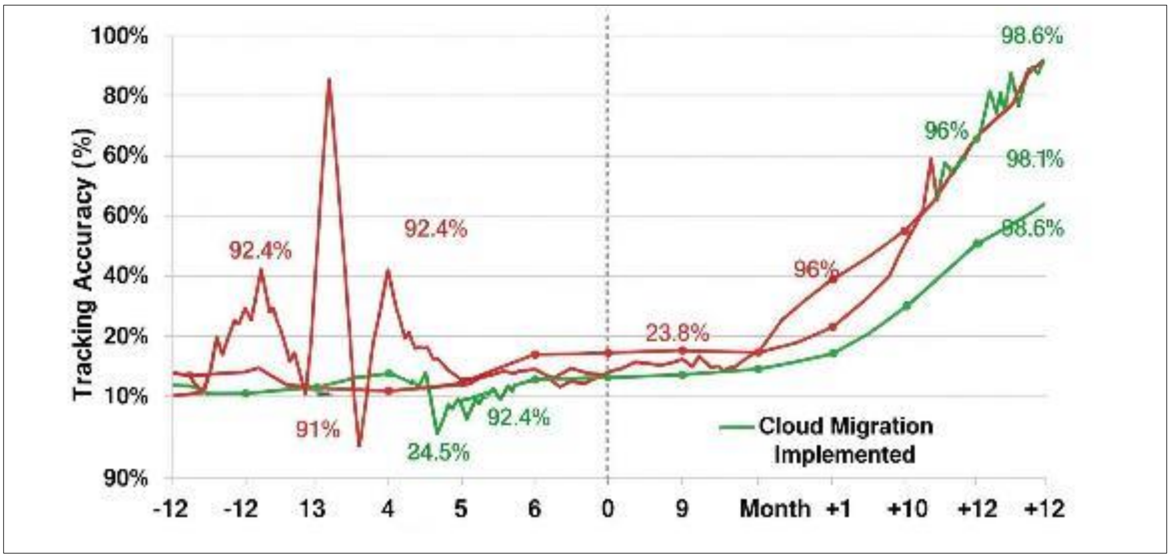

Figure 4 Improvement in Shipment Tracking Accuracy

5.4. Customs Clearance Time

Due to improved document digitization, consolidated compliance checks, and AI-powered anomaly detection in cargo declarations, the average time of customs clearance had an overall improvement of 27% (a reduction from 7.4 to 5.4 hours). This reduction in clearance time not only reduces the idle time of the vessels but also boosts the overall efficiency of cargo operations. The benefits of cloud-based customs processing are vividly demonstrated in the side-by-side analysis of Figure 5.

Figure 5 Acceleration of Customs Clearance through Cloud Integration

6. Conclusion

Transitioning to the cloud, especially for sea and port to port deliveries, has a unique chance to enhance data precision, streamline operations, and facilitate prompt decision-making in the shipping sector. Shifting away from premised systems to cloud architecture means that problems like data silos, lack of scalability, and delayed communications between stakeholders would be addressed. Certainly, after the migration, the gains will be evident: a 23% decrease inside container dwell time, 19% increased berth turnaround efficiency, tracking accuracy improving to 98.6%, and a 27% decrease in customs clearance time. The gains are indisputable and exemplify the advantages of leveraging cloud services in shipping. While agility in the face of disruptions, AI and blockchain integration, regulation compliance, and others stand as advantages, the high initial costs, data privacy and change management pose challenges. The move to the cloud provides collaborators with competitive, clear-cut, and green maritime operations and positions such companies to achieve quicker turnarounds, higher throughput, and maintain a stronger footing in global shipping.

References

[1] International Maritime Organization (IMO). International Shipping Facts and Figures. London: IMO Publications; 2023.

[2] United Nations Conference on Trade and Development (UNCTAD). Review of Maritime Transport 2022. Geneva: UNCTAD; 2022.

[3] Mell P, Grance T. The NIST definition of cloud computing. NIST Spec Publ 800-145. Gaithersburg, MD: National Institute of Standards and Technology; 2011.

[4] United Nations Conference on Trade and Development (UNCTAD). Port Performance Indicators: Dwell Time Analysis. Geneva: UNCTAD; 2021.

[5] World Bank. Container Port Performance Index 2021. Washington, DC: The World Bank Group; 2021.

[6] International Maritime Organization (IMO). Guidelines on Maritime Cyber Risk Management. Resolution MSC.428(98). London: IMO Publications; 2021.

[7] Singla N, Chahat, Nisha, Harnoor. A review paper on cloud computing. In: 2022 2nd International Conference on Innovative Sustainable Computational Technologies (CISCT); 2022 Dec; Dehradun, India. IEEE; 2022. p. 1–4.

[8] Luca F, Yannes F, Zoran L. Digital transformation in the shipping industry: a network-based bibliometric analysis. J Mar Sci Eng. 2025;13(5):894.

[9] Tao J, Zhang D, Wan C. Review of maritime shipping networks research in the context of the Belt and Road Initiative. In: 2021 6th International Conference on Transportation Information and Safety (ICTIS); 2021 Nov; Wuhan, China. IEEE; 2021. p. 183–90.

[10] Xu M, Pan Q, Xia H, Masuda N. Estimating international trade status of countries from global liner shipping networks. R Soc Open Sci. 2020;7(10):200386.

[11] Accenture. Digital Transformation in Shipping: Cloud as a Catalyst. Accenture Insights; 2022.

[12] Poulis K, Galanakis GC, Triantafillou GT, Poulis E. Value migration: digitalization of shipping as a mechanism of industry dethronement. J Shipp Trade. 2020;5(1):9.

[13] Zeng F, Chen A, Xu S, Chan HK, Li Y. Digitalization in the maritime logistics industry: a systematic literature review of enablers and barriers. J Mar Sci Eng. 2025;13(4):797.

[14] Al Mazroui TSS, Al Alawi MMS, Al Wahaibi KSH, Al Amri BBS, Thottoli MM. Maturity of digital transformation in the shipping industry: a case study among enterprises in Gulf Cooperation Council (GCC) countries. Kapal J Ilmu Pengetah Teknol Kelaut. 2023;20(1):115–23.

[15] International Association of Ports and Harbors (IAPH), World Bank. Port community systems: design, development and operation. Washington, DC: World Bank Group; 2023

[16] Constante JM. International case studies and good practices for implementing Port Community Systems. 2019.

[17] Othman A, El-Gazzar S, Knez M. A framework for adopting a sustainable smart sea port index. Sustainability. 2022;14(8):4551.

[18] Kaštelan N, Vidan P, Assani N, Miličević M. Digital horizon: assessing current status of digitalization in maritime industry. Trans Marit Sci. 2024;13(1).

[19] Portbase. Migrating the Dutch national PCS to AWS cloud. Portbase B.V.; 2023.

[20] Arin J, Velez G, Bustamante P. A C-ITS architecture for MEC and cloud native back-end services. IEEE Access. 2024;12:64531–50.

[21] VesselAI Consortium. Extreme-scale maritime analytics and digital twins architecture. Brussels: European Commission CORDIS; 2023.

[22] International Maritime Organization (IMO). Maritime cyber risk management in safety management systems (MSC-FAL.1/Circ.3-Rev.3). London: IMO Publications; 2024.

[23] Pan H, Zou N, Wang R, Ma J, Liu D. Artificial intelligence usage and supply chain resilience: an organizational information processing theory perspective. Systems. 2025;13(9):724.

[24] Jensen T, Hedman J, Henningsson S. How TradeLens delivers business value with blockchain technology. MIS Q Exec. 2019;18(4).

[25] Balci G, Surucu-Balci E. Blockchain adoption in the maritime supply chain: examining barriers and salient stakeholders in containerized international trade. Transp Res Part E Logist Transp Rev. 2021;156:102539.

[26] Port of Rotterdam Authority. Rotterdam port digital twin and IoT platform. Rotterdam: Port of Rotterdam; 2023.

[27] Lv T, Tang P, Zhang J. A real-time AIS data cleaning and indicator analysis algorithm based on stream computing. Sci Program. 2023;2023(1):8345603.