*Review Article*

# Transformation Model and Systematic Approach for Smart Maritime Logistics: A Literature Analysis

**Nur Azisah [1],\*, Vivian Karim Ladesi[1], Tri Mulyono [1], Intan P. Wangi [1] and Chairul Paotonan[2]**

[1]  Applied Undergraduate Study Program of Port Management and Maritime Logistics, Universitas Negeri Jakarta, Indonesia

[2] Department of Ocean Engineering, Universitas Hasanuddin, Indonesia

 **\*** Correspondence author: nurazisah@unj.ac.id; Tel.: +62-81243268578

**Abstract:** This article examines advanced technology applications in maritime logistics through a systematic literature review and bibliometric analysis. Using established PRISMA guidelines, 72 relevant articles were selected from major academic databases and analyzed using bibliometric tools to identify research trends and key findings. The research identifies how Internet of Things (IoT), artificial intelligence (AI), blockchain, and automation technologies enhance operational efficiency and environmental sustainability in maritime logistics. Results demonstrate that these technologies improve supply chain visibility and control while reducing greenhouse gas emissions and energy consumption. The analysis reveals that IoT enables real-time monitoring, AI supports intelligent decision-making, blockchain enhances transparency and security, and automation reduces manual workload. Environmental sustainability emerges as a key focus, with technologies optimizing port operations and minimizing environmental impact. This research emphasizes the need for a holistic approach to smart maritime logistics that integrate technology, management, and sustainability. The findings contribute to academic literature and provide practical insights into the maritime industry's adoption of advanced technologies to achieve improved operational efficiency and sustainability.

## 1. Introduction

The use of the word "SMART" has become popular in describing technological advances used by an industry. However, there is no standardization of a company called smart that is a reference. In the maritime industry, the word smart port is a trend that many countries have begun to develop. The development of technology has advanced increasingly from the emergence of 4.0 technology to begin to be developed into 6.0 technology which highlights the increasing importance of advanced technology in maritime logistics and smart ports. Twin digital technologies, IoT, big data, and cloud computing are identified as key disruptive technologies in the marine transportation industry [1]. This technology

allows for increased efficiency, responsiveness, and sustainability in port operations [2].

In the field of maritime logistics, a data-driven approach is to address challenges such as low visibility and system rigidity [3]. The application of this technology aims to create business value through a holistic perspective on the life cycle of goods production data and logistic processes [3], [4]. Overall, the trend of smart word usage emphasizes the transformative potential of advanced ICTs in maritime logistics and production, where the application of advanced technologies such as the Internet of Things (IoT) that enables connectivity and communication between devices in maritime logistics systems, such as sensors on ships, containers, and port facilities,

which generates real-time data to improve visibility and control over the movement of goods [5]–[7]. Next is artificial intelligence (AI) which is used for data analysis and intelligent decision-making, such as predictive analytics for route optimization and payload planning [8]. Then blockchain offers solutions to improve transparency, security, and efficiency in logistics transactions and supply chain management [9], [10]. On the other hand, automation in the form of Automated Guided Vehicles (AGVs) and advanced ship traffic management systems help to improve efficiency and reduce human error [11]. This transformation aims not only to improve operational efficiency but also to achieve environmental and economic sustainability. Although the benefits of this technology have been widely recognized, its application and adoption still face various challenges and obstacles that require further research.

The development of increasingly sophisticated technology requires the service provider industry, especially the one discussed in this study, namely the aspects involved in maritime logistics activities to maintain their existence and face global competition. Previous studies that mostly took the topic of smart port, sustainable port, digitalization port and green port while in logistics as a process that occurs in a port is still a topic that is rarely discussed. Researchers see from the perspective that without a logistical process, the port will lose its function. Therefore, in addition to making a port a smart service provider infrastructure using modern technology, the flow of goods must also be modern. Thus, this research will discuss the implementation of Artificial Intelligence-based technology in realizing smart maritime logistics.

With a focus on technological innovation and sustainability, this article is expected to contribute significantly to academic literature and provide practical insights for the maritime industry, especially in realizing smart maritime logistics. In addition, the results of this research are expected to help overcome challenges in technology adoption and encourage faster and more effective transformation as well as efficient and sustainable [12], [13].

## 2. Materials and Methods

The Systematic Literature Review (SLR) method is used in this study to compile a systematic and transparent review of the existing literature[14]–[16]. SLRs allow researchers to collect, evaluate, and synthesize findings from a variety of relevant studies, providing an in-depth and comprehensive understanding of the topic being researched [12], [17], [18]. Through the analysis of the existing literature, this study identifies the key technologies used in maritime logistics operational areas such as port areas (Balci AND Surucu-Balci 2021; Paraskevas ET AL. 2024; Sarabia-Jácome David, Carlos E., Manuel Esteve 2020)ship [15], [19], [21], [22] and also logistics management [22]–[24] and the movement of goods by utilizing maritime infrastructure and transportation facilities in Smart Maritime Logistics.

Based on the objectives to be achieved, this study uses the systematics literature review (SLR) method [14], [15], [25] and apply bibliometric analysis to provide an overview in the Smart Maritime Logistics research study [4], [14]. This research focuses on the implementation of a systematic literature review (SLR) with the aim of: (i) describing the main categories and themes in the research topic, and (ii) identifying gaps between studies to facilitate future research [15]. Meanwhile, bibliometric analysis as one of the methods of literature review is "systematic, transparent, and reproducible" by providing and mapping quantitative data objectively and reliably related to VoSviewer [26]. Because the topic of discussion about "Smart Maritime Literacy" discussed in this study is a new topic, there are not many publication articles that use this sentence in the title, so this research is carried out more carefully utilizing articles that have been published and discussing the implementation of maritime logistics that has utilized technology globally. Systematic literature review is very appropriate to be used to investigate research fields that are still in the early stages of their development [15], [26]–[28].

In this study, bibliographic data was collected from a leading academic database,

namely Scopus [15], [25]–[29], Science Direct and Semantic Scholar as well as as supporting data used databases from Google Scholar. The data was extracted by keyword searches in June to July 2024. All articles on the topic of technology utilization in supporting maritime logistics activities were selected to be then filtered using systematic literature review.
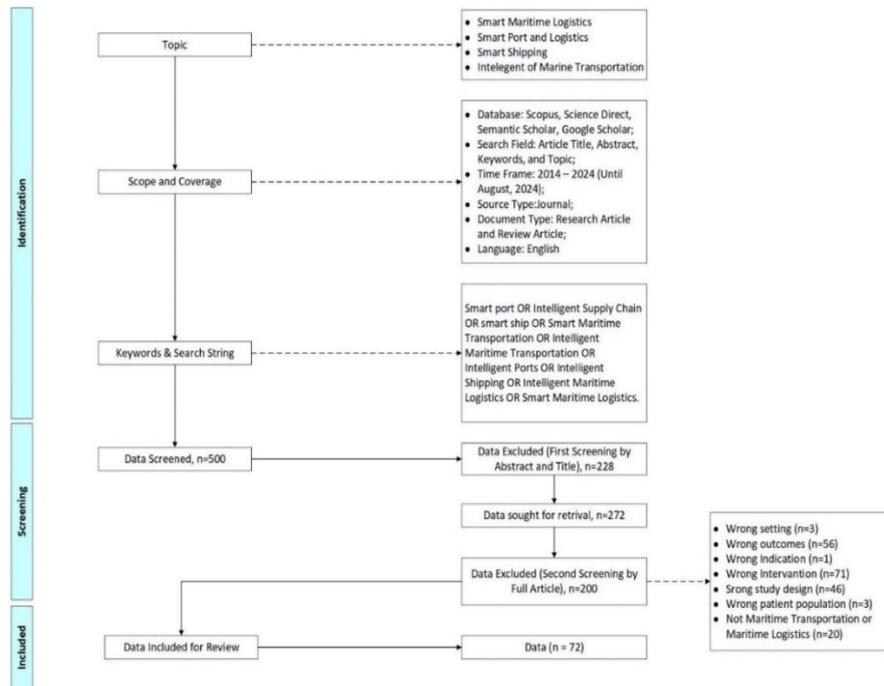


Figure 1. Article filtering results

The keywords used in this study consist of "Smart Port OR Intelligent Supply Chain OR Smart Ship OR Smart Maritime Transportation OR Intelligent Maritime Transportation OR Intelligent Ports OR Intelligent Shipping OR Intelligent Maritime Logistics OR Smart Maritime Logistics".

The articles used in this study are articles in English and have been published in the last 10 years, namely in the period 2014-2024. The selected articles are "research articles" and "review articles". Based on the initial search results, 1,105 articles were found to be filtered. The article screening process is carried out in several stages, namely (i) screening based on article titles and abstracts; (ii) screening based on the subject matter of the article; and (iii) screening based on the entire content of the article. Finally, all articles are manually filtered based on their relevance to smart maritime logistics in ports, ships and supply chain

management. This article excludes irrelevant articles due to (1) keyword homonimitation issues, e.g. where "smart port" is part of a new route architecture in a communication network; (2) focusing on autonomous shipping, intelligent shipping, and intelligent ports; (3) a logistics process that only focuses on logistics activities for regional economic development. A final sample of 72 articles was selected for bibliometric analysis and systematic literature review as shown in Figure 1. To extract and present the results of the analysis, this study uses VOSviewer software version 1.6.19 developed by Nees Jan van Eck and Ludo Waltman [30].

The bibliometric analysis results viewer software in VOSviewer version 1.6.19 is used to analyze keyword usage and the connection between authors. The research mapping utilizes text data (RIS files) exported from the Mendeley Preference Manager, which serves as a reference

tool in systematic literature reviews (SLRs). The binary counting approach generates a large circle region that represents the most frequently occurring occurrences of keywords from each article. This means that the larger the circle area in the bibliometric results, the more often the keyword is used.

This study has several limitations that should be considered when interpreting its findings. Firstly, the systematic literature review and bibliometric analysis approach employed in this research is highly dependent on the scope and quality of the selected articles, which may result in underrepresentation of local contexts, particularly those of Indonesia and Southeast Asia, in the analyzed literature. Furthermore, most references are sourced from international, English-language journals, potentially overlooking important developments or case studies published in local languages or national journals. The study also does not provide an in-depth discussion of the readiness of

infrastructure, policy frameworks, and human resources at the national level, all of which could pose significant challenges to the implementation of advanced technologies in Indonesian ports. Therefore, the results and recommendations presented should be carefully adapted to the actual conditions on the ground before being widely adopted.

## 3. Results

### 3.1. Review of Screening Articles

Based on the results of filtering articles from various sources, it is known that there are 72 articles selected as data in research on the application of technology in efforts to realize smart logistics in the maritime logistics industry. The findings of the review are related to the technology used, environmental sustainability and implementation in logistics processes and management. The selected articles are shown in Table 1 below.

Table 1. Results of Article Review

| No | Title | Year of Publication | Country |
|---|---|---|---|
| 1 | An information architecture to enable track-and-trace capability in Physical Internet ports [31] | 2021 | Canada |
| 2 | Advancing sustainability through digital servitization: An exploratory study in the maritime shipping industry [32] | 2023 | No specific country; |
| 3 | A survey on blockchain technology in the maritime industry: challenges and future perspectives [33] | 2024 | Singapore |
| 4 | A framework for building a smart port and smart port index [29] | 2020 | Mediterranean area and mentions Germany (Hamburg) and Singapore |
| 5 | A Blockchain-based Digital Twin for IoT deployments in logistics and transportation [34] | 2024 | Spain |
| 6 | A collaborative approach to manage continuous service innovation [35] | 2024 | European |
| 7 | A smart port development: Systematic literature and bibliometric analysis [14] | 2023 | Singapore and Rotterdam |
| 8 | Application of smart logistics technologies in the organization of multimodal cargo delivery [36] | 2022 | Kyrgyzstan |
| 9 | A blockchain-based architecture and smart contracts for an interoperable Physical Internet [37] | 2023 | Greece |
| 10 | A scalable real-time tracking and monitoring architecture for logistics and transport in RoRo terminals [38] | 2019 | Morocco |
| 11 | Assessing the resilience of sustainable autonomous shipping: New methodology, challenges, opportunities [39] | 2023 | European |
| 12 | Blockchain adoption in sustainable supply chains for Industry 5.0: Amultistakeholder perspective [40] | 2022 | No specific country; |
| 13 | Augmented Lagrangian relaxation-based coordinated approach for global synchromodal transport planning with multiple operators [41] | 2024 | Asia and Europe |
| 14 | Blockchain applications and architectures for port operations and | 2021 | Denmark |

| No | Title | Year of Publication | Country |
|---|---|---|---|
| | logistics management [5] | | |
| 15 | Developing a digital transformation maturity model for port assessment in archipelago countries: The Indonesian case [42] | 2024 | Indonesia |
| 16 | Digital information in maritime supply chains with blockchain and cloud platforms: Supply chain capabilities, barriers, and research opportunities [9] | 2024 | United Kingdom |
| 17 | Blockchain technology in supply chain operations: Applications, challenges and research opportunities [43] | 2020 | Norway |
| 18 | Connected freight transport advances and benefits[44] | 2023 | United Kingdom |
| 19 | C-Ports: a proposal for a comprehensive standardization and implementation plan of digital services offered by the "Port of the Future" [45] | 2022 | Italy |
| 20 | Challenges in the Digital Transformation of Ports [7] | 2023 | ports of Hamburg, Antwerp, Singapore, and Tianjin in China, |
| 21 | Blockchain adoption in the maritime supply chain: Examining barriers and salient stakeholders in containerized international trade [19] | 2021 | Greece |
| 22 | Critical infrastructures cybersecurity and the maritime sector [46] | 2020 | Global |
| 23 | Blockchain in the shipping industry: A proposal for the use of blockchain for SMEs in the maritime industry [47] | 2023 | Portugal |
| 24 | Digital Technique-Enabled Container Logistics Supply Chain Sustainability Achievement [1] | 2023 | China |
| 25 | DMLBC: Dependable machine learning for seaports using blockchain technology [48] | 2024 | China, specifically referencing the case of Dandong Port |
| 26 | Digital twins for logistics and supply chain systems: Literature review, conceptual framework, research potential, and practical challenges [49] | 2023 | Global |
| 27 | Industry 4.0 in the port and maritime industry: A literature review. [28] | 2020 | Spain |
| 28 | Digital twin-enabled smart maritime logistics management in the context of industry 5.0. [4] | 2024 | China |
| 29 | Digital transformation in the maritime transport sector [50] | 2021 | Europe, particularly Italy and Croatia, as indicated by the supported projects mentioned |
| 30 | Digital platform for maritime port ecosystem: Port of Hamburg case [51] | 2021 | Germany |
| 31 | Emerging approaches applied to maritime transport research: Past and future. [52] | 2021 | Germany (Hamburg), the Netherlands (Rotterdam), Canada (Quebec), and Singapore. |
| 32 | e-Maritime for automating legacy shipping practices [53] | 2016 | European |
| 33 | Improving the security of containers in port related supply chains [54] | 2016 | European |
| 34 | Multi-element integrated design of marine landscape in sustainable smart ports [55] | 2024 | china |
| 35 | Maritime transport management in Kuwait toward an automated port logistical city [56] | 2022 | Kuwait |
| 36 | Is blockchain a solution for logistics and freight transportation problems? (2020) | 2020 | Slovenia |
| 37 | Maritime terminals' cargo handling equipment cooperation leveraging IoT and edge computing: The ASSIST-IoT approach [57] | 2023 | European Union |
| 38 | Operational adaptation of ports with maritime autonomous surface ships [58] | 2024 | European Union (EU) |
| 39 | Industry 5.0 – Past, Present, and Near Future [59] | 2023 | No specific country; |
| 40 | Innovative cognitive data platform to improve processes in European seaports. [60] | 2023 | European ports |
| 41 | Managing a blockchain-based platform ecosystem for industry- | 2022 | Global |

| No | Title | Year of Publication | Country |
|---|---|---|---|
| | wide adoption: The case of TradeLens.[61] | | |
| 42 | Perspectives for ports development, based on automated container handling technologies [62] | 2023 | Italy |
| 43 | Port 4.0: a conceptual model for smart port digitalization [27] | 2023 | Global |
| 44 | Port and city integration: transportation aspect [63] | 2021 | China (Shanghai) and European countries (Hamburg and Rotterdam). |
| 45 | Ports Digitalization Level Evaluation [64] | 2021 | No specific country |
| 46 | Port performance evaluation and selection in the Physical Internet [6] | 2022 | Global |
| 47 | On the evolution of maritime ports towards the Physical Internet [65] | 2021 | Netherlands, Port of Rotterdam. |
| 48 | Performance analysis of LogisticChain: A blockchain platform for maritime logistics [66] | 2024 | Global |
| 49 | Smart Ports in Industry 4.0: A Systematic Literature Review [15] | 2024 | South Korea |
| 50 | Seaport data space for improving logistic maritime operations [20] | 2019 | Spain, specifically focusing on the Valencia Seaport |
| 51 | Smart, green, and sustainable: unveiling technological trajectories in maritime port operations [67] | 2024 | Global |
| 52 | Security and QoS issues in blockchain enabled next-generation smart logistic networks: A tutorial [68] | 2022 | Australia |
| 53 | Shipping in the era of digitalization: Mapping the future strategic plans of major maritime commercial actors [22] | 2022 | Baltic Sea region |
| 54 | Smart technologies and port operations: Optimal adoption strategy with network externality consideration. [69] | 2023 | United States |
| 55 | Spanish approach for the Smart Digital Ports through highly automated logistics [70] | 2023 | Spain |
| 56 | Prospects for using blockchain technology in transportation and supply chain management. [71] | 2023 | Slovakia |
| 57 | Smart Logistics in the development of Smart Cities. [16] | 2019 | Poland |
| 58 | Assessing innovation in transport: an application of the Technology Adoption (TechAdo) model to Maritime Autonomous Surface Ships (MASS) [72] | 2021 | Norway |
| 59 | Multi-aspect applications and development challenges of digital twin-driven management in global smart ports. [73] | 2021 | Global |
| 60 | Supply Chain 4.0 performance measurement: A systematic literature review, framework development, and empirical evidence [25] | 2022 | no specific country |
| 61 | Synchronization in synchromodality [74] | 2023 | Europe |
| 62 | The effect of digital adoption and service quality on business sustainability through strategic alliances at port terminals in Indonesia. [23] | 2024 | Indonesia |
| 63 | Sustainability of freight transport through an integrated approach: the case of the eastern sicily port system. [75] | 2020 | Italy |
| 64 | The key challenges of blockchain implementation in maritime sector: summary from literature and previous research findings. [76] | 2023 | Denmark and Finland, |
| 65 | The internet of things for smart ports [77] | 2022 | China |
| 66 | System federation as means to achieve seamless logistics operations: Implementation gaps and best practices in selected multimodal cases from Greece [78] | 2023 | Greece |
| 67 | Technological trajectories and scenarios in seaport digitalization [24] | 2021 | Finland |
| 68 | Understanding the barriers of port logistics for effective operation in the Industry 4.0 era: Data-driven decision making. [79] | 2021 | India |
| 69 | What is known about smart ports around the world? A benchmarking study [80] | 2024 | Global |
| 70 | VITAL-5G: a novel 5G-enabled platform for vertical innovations in transport and logistics [81] | 2023 | Belgium |
| 71 | The Promethee method and its applications in the maritime | 2023 | Croatia |

| No | Title | Year of Publication | Country |
|----|-------|---------------------|---------|
|    | industry: a review of studies from the Hrčak database. [82] | | |
| 72 | Towards Shipping 4.0. A preliminary gap analysis [21] | 2020 | Italy |

Based on Table 1, it is known that the publication of articles for 10 years, especially articles that discuss smart and sustainable maritime logistics activities, is carried out by many reputable international journals. Based on the data obtained, it is known that articles discussing topics related to the use of technology in the development of maritime logistics activities are most widely published in the 2023-2024 range, while in the 2014-2016 period articles with the topic of digitalization or sustainability in the maritime logistics process have not been in great demand. Article data obtained after the filtering process the data can be visualized in the form of graphs as shown in Figure 2 below. Based on Figure 3, it is known that the countries with the most research on the development of maritime logistics activities are in countries in Europe, followed by China and Singapore. This is a finding that also proves that the development of ports in these countries is the fastest and brings ports in the country to the top 5 busiest ports in the world based on World Ranking 2023-2024 data.
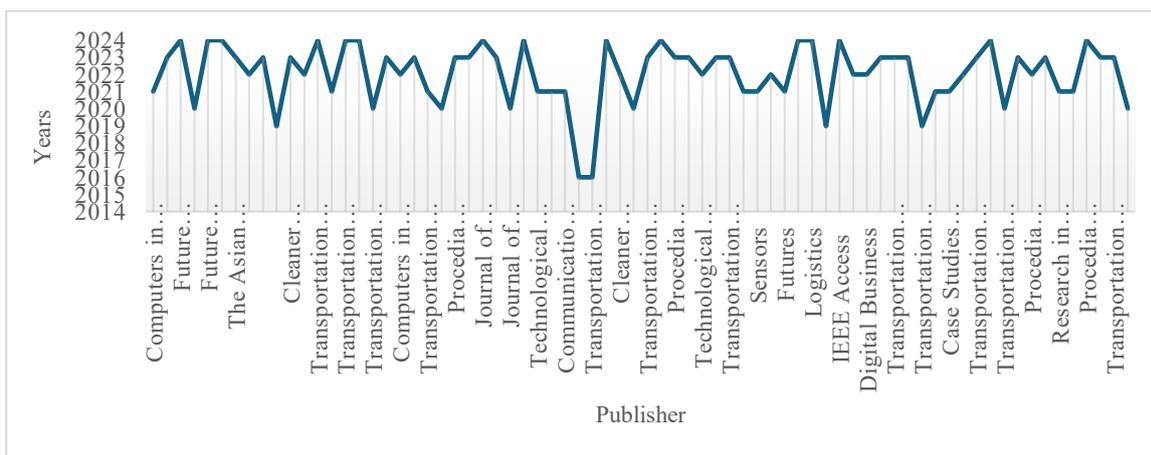


Figure 2. Distribution of Publication of Articles filtered over 10 years (2014-2024)
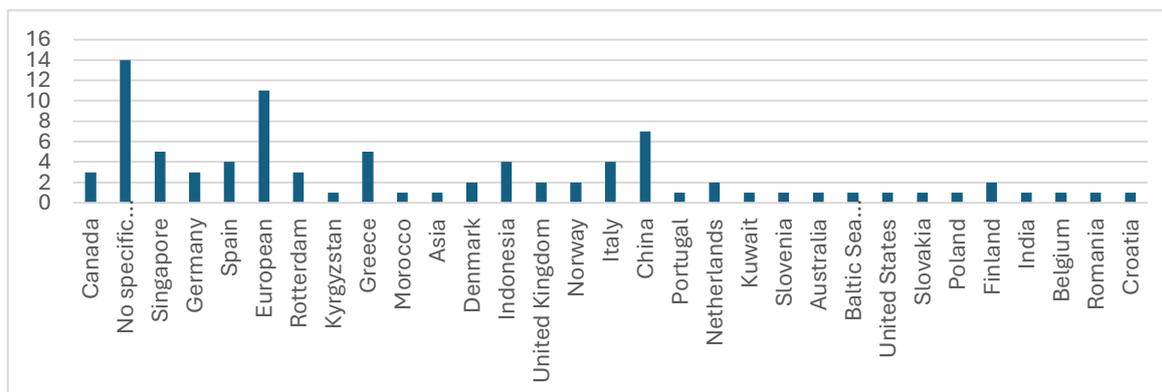(Author's analysis, 2024)



Figure 3. Distribution of Countries of Origin of Research
(Author's analysis, 2024)

Figure 4. Visualization Network Keyword Matching (Elaborated with VOSviewer)

## 3.2. Trends in Smart Maritime Logistics

### 3.2.1. Key Indicators of Smart Maritime Logistics

To develop the concept of intelligent maritime logistics, this study tries to identify through several indicators, namely the use of technology, implementation areas in the maritime logistics process and benefits to environmental sustainability. In general, it is known that the logistics management system is described in the following Figure 5.



Figure 5 Maritime Logistics Management System [83]

The main function of the maritime logistics system is to move shippers from one place to another through ports. Maritime logistics through shipping activities also provides other logistics services, such as pick-up services, delivery notifications, special handling services for customers who need certain services, bill of lading (B/L) in/out, container tracking and information, and intermodal services [5], [22]. To ensure that cargo can be passed smoothly and quickly to the next stage in the logistics system, port/terminal operations in a modern logistics system involve not only loading/unloading cargo to/from ships, but also a variety of value-added services including warehousing, storage and packaging as well as the arrangement of land transportation modes [78], [79].

Each maritime logistics actor has a role in the implementation of shipping goods through sea transportation. Shipping goods through maritime logistics activities is required to be integrated with each other [50] to meet customer desires and maintain existence in the logistics field. To fulfill the integration between maritime logistics actors, the use of digitized technology is needed to support the smooth process. One of them is the implementation of a digitalization system that not only connects humans but also

connects humans with the supporting infrastructure for maritime logistics activities while maintaining environmental sustainability factors as shown in Figure 6.
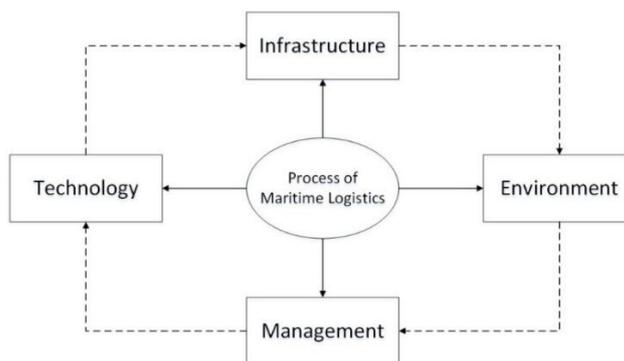


Figure 6 Findings of the implementation flow of the smart maritime logistics concept
*(*Author's analysis, 2024*)*

Based on the results of bibliometric analysis, it is known that the concept of smart maritime logistics is influenced by 4 main indicators, namely the connectivity between infrastructure, technology, environment and management in the maritime logistics process. These indicators are integrated with each other to realize a more optimal, efficient maritime logistics process and maximize coordination and collaboration between the port, the shipping industry and the owner of goods.

### 3.2.2. Implementation of Smart Maritime Logistics Indicators

The findings of this study provide valuable practical guidance for both Indonesia and the broader Southeast Asian port industry. For Indonesia, these insights can support the formulation of policies and workforce development programs to accelerate digital technology adoption in port and logistics operations, with pilot projects in major ports serving as a foundation for broader implementation. Regionally, Southeast Asian ports are encouraged to collaborate on technology standardization and data exchange protocols, develop tailored smart port roadmaps, and invest in digital infrastructure and automation. Partnerships among government, industry, and academia, as well as a focus on cybersecurity and environmental monitoring, are essential to ensure efficient, secure, and sustainable port operations across the region.

a.  Infrastructure Connectivity

Connectivity and system integration [16], [44] It is the main focus in realizing infrastructure connectivity that includes the integration of various physical and digital components in the maritime logistics system. Implementation of the concept of smart maritime logistics using Internet of Things (IoT) Technology [57] to play a critical role in creating a connected network, enabling real-time monitoring and data collection. Optimization of the use of RFID sensors and tags to track container movements [61], environmental conditions, and operational equipment conditions. This IoT implementation improves visibility and control over the movement of goods, reduces ship waiting times, and optimizes resource allocation which is a key factor in achieving efficient operations.

b.  Technology

Advanced technologies such as artificial intelligence (AI) and blockchain are also important indicators in smart maritime logistics. AI is used for data analysis and intelligent decision-making [27], [69], such as predictive analytics for route optimization and load planning. AI algorithms can process data generated by IoT devices to identify patterns, predict equipment maintenance needs, and optimize operational workflows in maritime logistics activities. For example, predictive maintenance powered by AI can predict equipment failure before it occurs [57] thereby reducing downtime and maintenance costs. Additionally, AI-driven decision support systems can improve safety [6] by analyzing historical data to improve navigation and reduce the risk of

accidents in the port environment.

Blockchain [37], [43], offering solutions to improve transparency, security, and efficiency in logistics transactions and supply chain management. By providing a decentralized and immutable ledger, the blockchain facilitates the secure sharing of data [40] among stakeholders, increasing trust in the supply chain. The technology also allows for the automation of administrative processes [9] through the use of smart contracts, which can reduce manual workload and improve operational efficiency.

c. Environmental

Environmental sustainability is one of the main focuses in the implementation of smart maritime logistics. Advanced technology allows ports to optimize operations, leading to energy savings and reduced greenhouse gas emissions [45], [67]. For example, real-time data analytics can help manage ship traffic more effectively, reducing congestion and idle time at ports. This optimization not only increases the flow of goods but also minimizes fuel consumption and emissions from ships waiting to dock [72]. In addition to ports, environmental sustainability is a priority in the operation of transportation modes such as ships and cargo trucks [22], [44], [50], [74]. In the ship mode, the implementation of an environmentally friendly propulsion system is realized by using electrical energy sources to reduce dependence on fossil fuels. In the mode of truck transportation, especially trucks in ports, a hybrid system has been implemented, namely trucks that are run using electric energy and environmentally friendly fuels such as LNG and biofuels to reduce air pollution. This eco-friendly technology not only helps the port meet international environmental regulations [35], [53], [84], such as the Sulphur Emission Control Area (SECA) and the International Maritime Organization's (IMO) greenhouse gas strategy, but also enhance the port's reputation as a responsible and sustainable entity.

d. Management

Modern maritime logistics management systems don't just involve loading and unloading cargo [36], but also a variety of value-added services such as warehousing, storage, and packaging. The use of digital technology such as digital twins [4], [49] allowing ports to simulate various scenarios and optimize their operations. A digital twin is a virtual replica of a physical asset that allows ports to monitor and manage operations in real-time, as well as make more accurate planning and predictions.

AI-driven decision support systems can improve safety by analyzing historical data [46] to improve navigation and reduce the risk of accidents in busy port environments. In addition, the integrated port management system (Port Community Systems) improves coordination between various stakeholders at the port, including port operators, ship managers, cargo agents, and customs authorities. The system digitizes document management to reduce the use of physical documents, speed up administrative processes, and improve operational efficiency [77][20].

## 4. Conclusion

Based on the comprehensive literature analysis of transformation models and systematic approaches in smart maritime logistics, this study reveals that the convergence of IoT infrastructure, AI-driven analytics, and blockchain technology creates a synergistic ecosystem that fundamentally transforms maritime operational efficiency while addressing contemporary sustainability imperatives. The research demonstrates that smart maritime logistics implementation generates substantial economic value through enhanced operational visibility, intelligent decision-making processes, and automated transaction systems that collectively reduce operational costs and improve supply chain performance.

The findings indicate that successful smart maritime logistics transformation requires strategic integration of technological capabilities with institutional readiness and regulatory frameworks, particularly as evidenced by the geographic concentration of implementation in technologically advanced regions. While the adoption of these integrated systems presents significant opportunities for operational optimization and environmental compliance, the analysis reveals critical implementation challenges including cybersecurity

vulnerabilities, workforce adaptation requirements, and regulatory harmonization complexities that demand strategic management attention.

The study concludes that advancing smart maritime logistics requires immediate research focus on interoperability standardization, comprehensive quantitative impact assessment, and geographic diversification of implementation studies to establish robust theoretical foundations and practical guidelines for industry-wide transformation. These research priorities are essential for developing scalable implementation frameworks that can accommodate diverse maritime economic contexts while maximizing the transformative potential of smart logistics technologies in the global maritime industry.

## References

[1] J. Lyu, F. Zhou, and Y. He, "Digital Technique-Enabled Container Logistics Supply Chain Sustainability Achievement," *Sustainability*, vol. null, p. null, 2023, doi: 10.3390/su152216014.

[2] B. Belmoukari, J. F. Audy, and P. Forget, "Smart port: a systematic literature review," *Eur. Transp. Res. Rev.*, vol. 15, no. 1, 2023, doi: 10.1186/s12544-023-00581-6.

[3] M. Zafarzadeh, M. Wiktorsson, and J. B. Hauge, "Capturing value through data-driven internal logistics : case studies on enhancing managerial capacity," *Prod. Manuf. Res.*, vol. 11, no. 1, 2023, doi: 10.1080/21693277.2023.2214799.

[4] F. Zhou, "Digital Twin-Enabled Smart Maritime Logistics Management in the Context of Industry 5.0," *IEEE Access*, vol. 12, pp. 10920–10931, 2024, doi: 10.1109/ACCESS.2024.3354838.

[5] R. W. Ahmad, H. Hasan, R. Jayaraman, K. Salah, and M. Omar, "Blockchain applications and architectures for port operations and logistics management," *Res. Transp. Bus. Manag.*, vol. 41, p. 100620, 2021, doi: https://doi.org/10.1016/j.rtbm.2021.100620.

[6] P. B. M. Fahim, J. Rezaei, B. Montreuil, and L. Tavasszy, "Port performance evaluation and selection in the Physical Internet," *Transp. Policy*, vol. 124, pp. 83–94, 2022, doi: https://doi.org/10.1016/j.tranpol.2021.07.013.

[7] F. Almeida, "Challenges in the Digital Transformation of Ports," pp. 548–568, 2023.

[8] O. Prokopenko, A. Orozonova, and A. Kydykov, "Application of smart logistics technologies in the organization of multimodal cargo delivery," vol. 00, 2022.

[9] E. Surucu-Balci, Ç. Iris, and G. Balci, "Digital information in maritime supply chains with blockchain and cloud platforms: Supply chain capabilities, barriers, and research opportunities," *Technol. Forecast. Soc. Change*, vol. 198, p. 122978, 2024, doi: https://doi.org/10.1016/j.techfore.2023.122978.

[10] E. Irannezhad, "Is blockchain a solution for logistics and freight transportation problems?," *Transp. Res. Procedia*, vol. 48, pp. 290–306, 2020, doi: https://doi.org/10.1016/j.trpro.2020.08.023.

[11] L. Heilig, S. Schwarze, and S. Voß, "An analysis of digital transformation in the history and future of modern ports," *Proc. Annu. Hawaii Int. Conf. Syst. Sci.*, vol. 2017-Janua, pp. 1341–1350, 2017, doi: 10.24251/hicss.2017.160.

[12] P. B. M. Fahim, J. Rezaei, B. Montreuil, and L. Tavasszy, "Port performance evaluation and selection in the Physical Internet," vol. 124, no. September 2020, pp. 83–94, 2022.

[13] A. Adiliya, "Analysing an integrated maritime transportation system: The case the port of Tenau Kupang as a potential transhipment port for South-East Indonesia," 2017, [Online]. Available: https://thesis.eur.nl/pub/40482/Thesis-Ana-Adiliya.pdf

[14] T. Y. Pham, "A smart port development: Systematic literature and bibliometric

analysis," *Asian J. Shipp. Logist.*, vol. 39, no. 3, pp. 57–62, 2023, doi: https://doi.org/10.1016/j.ajsl.2023.06.005.

[15] A. Paraskevas, M. Madas, V. Zeimpekis, and K. Fouskas, "Smart Ports in Industry 4 . 0 : A Systematic Literature Review," pp. 1–29, 2024.

[16] J. Korczak and K. Kijewska, "Smart Logistics in the development of Smart Cities," *Transp. Res. Procedia*, vol. 39, pp. 201–211, 2019, doi: https://doi.org/10.1016/j.trpro.2019.06.022.

[17] S. Pan, "Opportunities of Product-Service System in Physical Internet," vol. 83, no. March, pp. 473–478, 2023.

[18] M. Shahbakhsh, G. R. Emad, and S. Cahoon, "The Asian Journal of Shipping and Logistics," vol. 38, pp. 10–18, 2021.

[19] G. Balci and E. Surucu-Balci, "Blockchain adoption in the maritime supply chain: Examining barriers and salient stakeholders in containerized international trade," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 156, p. 102539, 2021, doi: https://doi.org/10.1016/j.tre.2021.102539.

[20] F. B. SARABIA-JÁCOME DAVID, CARLOS E., MANUEL ESTEVE, "Seaport Data Space for Improving Logistic Maritime Operations," *IEEE Access*, vol. 8, 2020, doi: 10.1109/ACCESS.2019.2963283.

[21] G. Aiello, A. Giallanza, and G. Mascarella, "Towards Shipping 4.0. A preliminary gap analysis," *Procedia Manuf.*, vol. 42, pp. 24–29, 2020, doi: https://doi.org/10.1016/j.promfg.2020.02.019.

[22] Y. Ichimura, D. Dalaklis, M. Kitada, and A. Christodoulou, "Shipping in the era of digitalization : Mapping the future strategic plans of major maritime commercial actors," vol. 2, 2022, [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2666954422000023

[23] D. R. Utama, M. Hamsal, R. K. Rahim, and A. Furinto, "The effect of digital adoption and service quality on business sustainability through strategic alliances at port terminals in Indonesia," vol. 40, no. November 2023, pp. 11–21, 2024, [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2092521223000585

[24] T. Inkinen, R. Helminen, and J. Saarikoski, "Technological trajectories and scenarios in seaport digitalization," *Res. Transp. Bus. Manag.*, vol. 41, p. 100633, 2021, doi: https://doi.org/10.1016/j.rtbm.2021.100633.

[25] K. Govindan, D. Kannan, T. B. Jørgensen, and T. S. Nielsen, "Supply Chain 4.0 performance measurement: A systematic literature review, framework development, and empirical evidence," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 164, p. 102725, 2022, doi: https://doi.org/10.1016/j.tre.2022.102725.

[26] M. Aria and C. Cuccurullo, "bibliometrix : An R-tool for comprehensive science mapping analysis," *J. Informetr.*, vol. 11, no. 4, pp. 959–975, 2017, doi: 10.1016/j.joi.2017.08.007.

[27] B. Behdani, "Port 4.0: a conceptual model for smart port digitalization," *Transp. Res. Procedia*, vol. 74, pp. 346–353, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.154.

[28] I. de la Peña Zarzuelo, M. J. Freire Soeane, and B. López Bermúdez, "Industry 4.0 in the port and maritime industry: A literature review," *J. Ind. Inf. Integr.*, vol. 20, p. 100173, 2020, doi: https://doi.org/10.1016/j.jii.2020.100173.

[29] A. Molavi, G. J. Lim, and B. Race, "A framework for building a smart port and smart port index," *Int. J. Sustain. Transp.*, vol. 14, no. 9, pp. 686–700, 2020, doi: https://doi.org/10.1080/15568318.2019.1610919.

[30] N. J. Van Eck and L. Waltman, "VOSviewer Manual," no. January, 2023.

[31] P. B. M. Fahim, R. An, J. Rezaei, Y. Pang,

B. Montreuil, and L. Tavasszy, "An information architecture to enable track-and-trace capability in Physical Internet ports," *Comput. Ind.*, vol. 129, p. 103443, 2021, doi: https://doi.org/10.1016/j.compind.2021.103443.

[32] C. A. González Chávez *et al.*, "Advancing sustainability through digital servitization: An exploratory study in the maritime shipping industry," *J. Clean. Prod.*, vol. 436, p. 140401, 2024, doi: https://doi.org/10.1016/j.jclepro.2023.140401.

[33] M. B. Farah, "A survey on blockchain technology in the maritime industry: Challenges and future perspectives," *Futur. Gener. Comput. Syst.*, vol. 157, pp. 618–637, 2024, doi: 10.1016/j.future.2024.03.046.

[34] S. Cuñat Negueroles *et al.*, "A Blockchain-based Digital Twin for IoT deployments in logistics and transportation," *Futur. Gener. Comput. Syst.*, vol. 158, pp. 73–88, 2024, doi: https://doi.org/10.1016/j.future.2024.04.011.

[35] T. Schiefer, D. Mahr, P. C. van Fenema, and K. Mennens, "A collaborative approach to manage continuous service innovation," *Technovation*, vol. 134, no. PG-103029, p. 103029, 2024, doi: https://doi.org/10.1016/j.technovation.2024.103029.

[36] A. Orozonova, S. Gapurbaeva, A. Kydykov, O. Prokopenko, G. Prause, and S. Lytvynenko, "Application of smart logistics technologies in the organization of multimodal cargo delivery," *Transp. Res. Procedia*, vol. 63, pp. 1192–1198, 2022, doi: https://doi.org/10.1016/j.trpro.2022.06.124.

[37] H. Niavis and A. M. Zafeiropoulou, "A blockchain-based architecture and smart contracts for an interoperable Physical Internet," *Transp. Res. Procedia*, vol. 72, pp. 2022–2029, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.684.

[38] M. A. M'hand, A. Boulmakoul, H. Badir, and A. Lbath, "A scalable real-time tracking and monitoring architecture for logistics and transport in RoRo terminals," *Procedia Comput. Sci.*, vol. 151, pp. 218–225, 2019, doi: https://doi.org/10.1016/j.procs.2019.04.032.

[39] K. Fjørtoft, S. P. Parvasi, D. A. Nesheim, L. A. Lien Wennerberg, O. E. Mørkrid, and H. N. Psaraftis, "Assessing the resilience of sustainable autonomous shipping: New methodology, challenges, opportunities," *Clean. Logist. Supply Chain*, vol. 9, p. 100126, 2023, doi: https://doi.org/10.1016/j.clscn.2023.100126.

[40] Z.-J. Wang, Z.-S. Chen, L. Xiao, Q. Su, K. Govindan, and M. J. Skibniewski, "Blockchain adoption in sustainable supply chains for Industry 5.0: A multistakeholder perspective," *J. Innov. Knowl.*, vol. 8, no. 4, p. 100425, 2023, doi: https://doi.org/10.1016/j.jik.2023.100425.

[41] W. Guo, Y. Zhang, W. Li, R. R. Negenborn, and B. Atasoy, "Augmented Lagrangian relaxation-based coordinated approach for global synchromodal transport planning with multiple operators," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 185, p. 103535, 2024, doi: https://doi.org/10.1016/j.tre.2024.103535.

[42] D. R. Utama, M. Hamsal, S. B. Abdinagoro, and R. K. Rahim, "Developing a digital transformation maturity model for port assessment in archipelago countries: The Indonesian case," *Transp. Res. Interdiscip. Perspect.*, vol. 26, p. 101146, 2024, doi: https://doi.org/10.1016/j.trip.2024.101146.

[43] P. Dutta, T.-M. Choi, S. Somani, and R. Butala, "Blockchain technology in supply chain operations: Applications, challenges and research opportunities," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 142, p. 102067, 2020, doi: https://doi.org/10.1016/j.tre.2020.1020

67.

[44] B. Gao, A. Garrido, and A. Walker, "Connected freight transport advances and benefits," *Transp. Res. Procedia*, vol. 72, pp. 3198–3204, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.873.

[45] P. Pagano, S. Antonelli, and A. Tardo, "C-Ports: A proposal for a comprehensive standardization and implementation plan of digital services offered by the 'Port of the Future,'" *Comput. Ind.*, vol. 134, p. 103556, 2022, doi: https://doi.org/10.1016/j.compind.2021.103556.

[46] J. I. Alcaide and R. G. Llave, "Critical infrastructures cybersecurity and the maritime sector," *Transp. Res. Procedia*, vol. 45, pp. 547–554, 2020, doi: https://doi.org/10.1016/j.trpro.2020.03.058.

[47] F. Lorenz-Meyer and V. Santos, "Blockchain in the shipping industry: A proposal for the use of blockchain for SMEs in the maritime industry," *Procedia Comput. Sci.*, vol. 219, pp. 807–814, 2023, doi: https://doi.org/10.1016/j.procs.2023.01.354.

[48] C. Durán, "DMLBC: Dependable machine learning for seaports using blockchain technology," *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 36, no. 1, 2024, doi: 10.1016/j.jksuci.2024.101918.

[49] T. V Le and R. Fan, "Digital twins for logistics and supply chain systems: Literature review, conceptual framework, research potential, and practical challenges," *Comput. Ind. Eng.*, vol. 187, p. 109768, 2024, doi: https://doi.org/10.1016/j.cie.2023.109768.

[50] E. Tijan, M. Jović, S. Aksentijević, and A. Pucihar, "Digital transformation in the maritime transport sector," *Technol. Forecast. Soc. Change*, vol. 170, p. 120879, 2021, doi: https://doi.org/10.1016/j.techfore.2021.120879.

[51] N. Kapkaeva, A. Gurzhiy, S. Maydanova, and A. Levina, "Digital Platform for Maritime Port Ecosystem: Port of Hamburg Case," *Transp. Res. Procedia*, vol. 54, pp. 909–917, 2021, doi: https://doi.org/10.1016/j.trpro.2021.02.146.

[52] R. Yan, S. Wang, L. Zhen, and G. Laporte, "Emerging approaches applied to maritime transport research: Past and future," *Commun. Transp. Res.*, vol. 1, p. 100011, 2021, doi: https://doi.org/10.1016/j.commtr.2021.100011.

[53] A. Morrall, J. Rainbird, T. Katsoulakas, I. Koliousis, and T. Varelas, "e-Maritime for Automating Legacy Shipping Practices," *Transp. Res. Procedia*, vol. 14, pp. 143–152, 2016, doi: https://doi.org/10.1016/j.trpro.2016.05.050.

[54] J. Scholliers, A. Permala, S. Toivonen, and H. Salmela, "Improving the Security of Containers in Port Related Supply Chains," *Transp. Res. Procedia*, vol. 14, pp. 1374–1383, 2016, doi: https://doi.org/10.1016/j.trpro.2016.05.210.

[55] N. Tang, "Multi-element integrated design of marine landscape in sustainable smart ports," *J. Sea Res.*, vol. 199, p. 102496, 2024, doi: https://doi.org/10.1016/j.seares.2024.102496.

[56] S. AlKheder *et al.*, "Maritime transport management in Kuwait toward an automated port logistical city," *Clean. Logist. Supply Chain*, vol. 3, p. 100031, 2022, doi: https://doi.org/10.1016/j.clscn.2022.100031.

[57] E. Garro *et al.*, "Maritime terminals' cargo handling equipment cooperation leveraging IoT and edge computing: The ASSIST-IoT approach," *Transp. Res. Procedia*, vol. 72, pp. 2864–2871, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.831.

[58] I. Kurt, "Operational adaptation of ports with maritime autonomous surface

ships," *Transp. Policy*, vol. 145, pp. 1–10, 2024, doi: 10.1016/j.tranpol.2023.09.023.

[59] J. Barata and I. Kayser, "Industry 5.0 – Past, Present, and Near Future," *Procedia Comput. Sci.*, vol. 219, pp. 778–788, 2023, doi: https://doi.org/10.1016/j.procs.2023.01.351.

[60] A. Belsa *et al.*, "Innovative cognitive data platform to improve processes in European seaports," *Transp. Res. Procedia*, vol. 72, pp. 1232–1239, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.582.

[61] M. Jovanovic, N. Kostić, I. M. Sebastian, and T. Sedej, "Managing a blockchain-based platform ecosystem for industry-wide adoption: The case of TradeLens," *Technol. Forecast. Soc. Change*, vol. 184, p. 121981, 2022, doi: https://doi.org/10.1016/j.techfore.2022.121981.

[62] D. Gattuso and D. S. Pellicanò, "Perspectives for ports development, based on automated container handling technologies," *Transp. Res. Procedia*, vol. 69, pp. 360–367, 2023, doi: https://doi.org/10.1016/j.trpro.2023.02.183.

[63] A. Gurzhiy, S. Kalyazina, S. Maydanova, and R. Marchenko, "Port and City Integration: Transportation Aspect," *Transp. Res. Procedia*, vol. 54, pp. 890–899, 2021, doi: https://doi.org/10.1016/j.trpro.2021.02.144.

[64] V. Paulauskas and L. Filina-dawidowicz, "Ports Digitalization Level Evaluation," 2021.

[65] P. B. M. Fahim, M. Martinez de Ubago Alvarez de Sotomayor, J. Rezaei, A. van Binsbergen, M. Nijdam, and L. Tavasszy, "On the evolution of maritime ports towards the Physical Internet," *Futures*, vol. 134, p. 102834, 2021, doi: https://doi.org/10.1016/j.futures.2021.102834.

[66] L. Ni, "Performance analysis of

LogisticChain: A blockchain platform for maritime logistics," *Comput. Ind.*, vol. 154, 2024, doi: 10.1016/j.compind.2023.104038.

[67] Y. A. V. S. and D. M. V. M. Maria Isabel Gerrero, "Smart , Green , and Sustainable : Unveiling Technological Trajectories in Maritime Port Operations," vol. 12, no. February, pp. 47713–47723, 2024, doi: 10.1109/ACCESS.2024.3376431.

[68] A. Vaghani, K. Sood, and S. Yu, "Security and QoS issues in blockchain enabled next-generation smart logistic networks: A tutorial," *Blockchain Res. Appl.*, vol. 3, no. 3, p. 100082, 2022, doi: https://doi.org/10.1016/j.bcra.2022.100082.

[69] K. Li, A. Gharehgozli, and J.-Y. Lee, "Smart technologies and port operations: Optimal adoption strategy with network externality consideration," *Comput. Ind. Eng.*, vol. 184, p. 109557, 2023, doi: https://doi.org/10.1016/j.cie.2023.109557.

[70] M. E. Vaca-Recalde *et al.*, "Spanish approach for the Smart Digital Ports through highly automated logistics," *Transp. Res. Procedia*, vol. 72, pp. 155–162, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.389.

[71] V. Bastiuchenko, M. Krajčovič, V. Biňasová, and L. Papánek, "Prospects for using blockchain technology in transportation and supply chain management," *Transp. Res. Procedia*, vol. 74, pp. 472–479, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.170.

[72] T. Fonseca, K. Lagdami, and J.-U. Schröder-Hinrichs, "Assessing innovation in transport: An application of the Technology Adoption (TechAdo) model to Maritime Autonomous Surface Ships (MASS)," *Transp. Policy*, vol. 114, no. PG-182-195, pp. 182–195, 2021, doi: https://doi.org/10.1016/j.tranpol.2021.09.005.

[73] K. Wang, Q. Hu, M. Zhou, Z. Zun, and X.

Qian, "Multi-aspect applications and development challenges of digital twin-driven management in global smart ports," *Case Stud. Transp. Policy*, vol. 9, no. 3, pp. 1298–1312, 2021, doi: https://doi.org/10.1016/j.cstp.2021.06.014.

[74] S. Sakti, L. Zhang, and R. G. Thompson, "Synchronization in synchromodality," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 179, p. 103321, 2023, doi: https://doi.org/10.1016/j.tre.2023.103321.

[75] M. Ignaccolo, G. Inturri, N. Giuffrida, V. Torrisi, and E. Cocuzza, "Sustainability of Freight Transport through an Integrated Approach: the Case of the Eastern Sicily Port System," *Transp. Res. Procedia*, vol. 45, pp. 177–184, 2020, doi: https://doi.org/10.1016/j.trpro.2020.03.005.

[76] S. Tsiulin, K. H. Reinau, and O.-P. Hilmola, "The key challenges of blockchain implementation in maritime sector: summary from literature and previous research findings," *Procedia Comput. Sci.*, vol. 217, pp. 348–357, 2023, doi: https://doi.org/10.1016/j.procs.2022.12.230.

[77] A. BOUHLAL, R. AITABDELOUAHID, and A. MARZAK, "The internet of things for smart ports," *Procedia Comput. Sci.*, vol. 203, pp. 819–824, 2022, doi: https://doi.org/10.1016/j.procs.2022.07.123.

[78] S. Dais and G. Ayfantopoulou, "System federation as means to achieve seamless logistics operations: Implementation gaps and best practices in selected multimodal cases from Greece," *Transp. Res. Procedia*, vol. 72, pp. 40–47, 2023, doi:

https://doi.org/10.1016/j.trpro.2023.11.320.

[79] B. D. Sarkar and R. Shankar, "Understanding the barriers of port logistics for effective operation in the Industry 4.0 era: Data-driven decision making," *Int. J. Inf. Manag. Data Insights*, vol. 1, no. 2, p. 100031, 2021, doi: https://doi.org/10.1016/j.jjimei.2021.100031.

[80] J. Basulo-Ribeiro, C. Pimentel, and L. Teixeira, "What is known about smart ports around the world? A benchmarking study," *Procedia Comput. Sci.*, vol. 232, pp. 1748–1758, 2024, doi: https://doi.org/10.1016/j.procs.2024.01.173.

[81] A. Kartakoullis *et al.*, "VITAL-5G: a novel 5G-enabled platform for vertical innovations in transport and logistics," *Transp. Res. Procedia*, vol. 72, pp. 4303–4310, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.341.

[82] R. Glavinović and L. Vukić, "The Promethee method and its applications in the maritime industry: a review of studies from the Hrčak database," *Transp. Res. Procedia*, vol. 73, pp. 94–101, 2023, doi: https://doi.org/10.1016/j.trpro.2023.11.896.

[83] Dong-Wook Song; Photis M Panayides., *A guide to contemporary shipping and port management*, Second edi. London: Kogan Page Limited, 2015.

[84] K. Lucenti, "SMART PORT MANUAL • STRATEGY AND ROADMAP to a Creative Commons IGO 3.0 Attribution-NonCommercial without Derivative Works license (CC-IGO 3.0 BY-NC-ND)," 2020.