Exploring Digital Supply Chain Practices in the Maritime Industry: A Systematic Literature Review

Mohammad Nazmuzzaman Hye [#1], Md. Mamun Habib[#2]

[#]*Tun Razak Graduate School (TRGS), Universiti Tun Abdul Razak*
Kuala Lumpur, Malaysia

[1]m.nazmuzzaman@ur.unirazak.edu.my

[2] mamunhabib@unirazak.edu.my

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***Abstract*— The maritime industry is undergoing a significant transformation with the integration of digital technologies to enhance efficiency, transparency, and security. This study systematically reviews the adoption of key digital technologies- such as blockchain, cloud computing, and internet of things (IoT)-with in the maritime sector. The findings reveal that digital supply chain (DSC) technologies enhance real-time data exchange, predictive analytics, and automation. Additionally, the study highlights the primary challenges hindering digital adoption, including infrastructure limitations, regulatory constraints, cybersecurity risks, and resistance to change.**

The contributions of this research are threefold. First, it provides comprehensive classification digital technologies in the maritime industry and their functional role in supply chain management. Second, it develops a conceptual framework that aligns digitalization Practices with performance outcomes in maritime logistics. Third, it identifies gaps in current research and proposes directions for future studies, particularly in improving interoperability, standardizing digital platforms, and assessing the long-term impact of DSC innovations. The study offers valuable insights for academics, industry practitioners, and policymakers aiming to optimize digital supply chain practices in the maritime industry.

***Keywords*—** *Digital Supply Chain, Maritime Logistics, Blockchain Technology, Cloud Computing, Internet of Things (IoT), Digitalization*

1. Introduction

Digital technologies have continuously altered human communication and interactions. Technological advancements and the introduction of digital devices, including personal computers and mobile phones, have revolutionized how societies interact and exchange information. Companies have also adapted to digital, leveraging new technologies to enhance supply chain and logistics services [2]. Traditional supply chains relied on multiple physical facilities across different locations to manage transportation and logistics. Supply Chains involve interconnected activities, requiring careful planning and coordination between suppliers and customers. However, technological advancements have redefined supply chain operations, with digital playing a transformative role in optimizing logistics processes [11].

The martime industry is among the sectors that have adopted digital supply chain (DSC) solutions. Since DSC continues to add value to organizations, companies increasignly focus on leveraging digitla technologies to enhance competitiveness. Martime firsm must integrate DSC strategies to streamline operations and improve supply chain efficiency. In today's data-driven supply chain model, physical warehouses are being replaced by cloud-based data centres, digital bandwidth is substituting traditional freight transport, and automated systems are transforming logistics management. Within digital supply chains, miltiple innovations-including Big Data, Augumanted Reality, Cloud Computing, Robotics, the Internet of Things (IoT), Self Driving Vehicles, 3D printing, Sensor Technology, and Unmanned Aeiral vechicles – are reshapping logistics networks [2],[6].

Recent studies indicate that DSC adoptions have contributed significantly to the maritime industry. However, realizing the full potential of DSC requires a comprehensive evaluation of how digitalization enhances maritime logistics. Most benefits of DSC require a comprehensive evaluation of how digitalization enhances maritime logistics. Most benefits of DSC stem from the operational solutions it enables, rather than the technology itself [7]. Within the maritime sector, the implementation of DSC offers several advantages, including improved supply chain coordination, real-time visibility, and cost optimization, which this study aims to examine.

This paper explores the context and applicatoin of DSC in

the maritime industry. It systematically reviews existing literature to identify and categorize digital supply chian practices relevent to maritime operations. The study compiles a comprehensive list of DSC practices, evaluates their significance, and highlights their potential to address key supply chain challenges. The findings offer valuable insights for academics and industry practioners, supporiting strategic decsion-making in digital supply chain management.

Furthermore, this study examines concpetual perspectives on DSC, recognizing gaps in exising lieterature and exploring how various aspects of DSC have been applied within the maritime industry. The analysis also reflects on administrative challenges, success factors, and implicatoins of digitalization in the maritime sector. Many potential benefits of DSC remain underutilized, as organizations have not fully explored how digitalization can optimize maritime suppply chains. Despite ongoing disucssion on evaluationg DSC effecitveness, limitd research hass assessed the concpetual framwork of DSC in maritme logistics. This study seeks to bridge that gap.

This paper is organized as follows: Section 2 outlines the Method of the study explaining the research approach, data collection strategy, and classification methodology. Section 3 presents a Reviwe of Literature on Maritime DSC, categorizing academic studies, industry reports, and books , along with an analysis of the advantages, weakness , and limitations of DSC in maritime supply chains. Section 4 explores Digital Supply Chain Practices in the maritime industry, identifying key technologies, adoption challenges, and success factors, Finally, Section 5 discuss findings, managerial implcations, limitations, and futre research directions.

2. Method of Study

This study follows a systematic literature review (SLR) approach to collect, categorize, and analyze existing research on Digital Supply Chain (DSC) applications in the maritime industry. The methodology ensures a structured, comprehensive, and replicable review by integrating academic research, industrial reports, and relevant publications.

Relevenet journal articles, books, and industrial reports were identified through a comprehensive online search, ensuring the inclusion of diverse perspectives on DSC applications in the maritime industry. The search targeted academic and industrial souces spanning multiple disciplines, including:

- Supply Chian manamgnet
- Operations Management
- Industrial Engineering
- Maritime Logistics
- Digitalization & Technology Adoption

Given the lack of standardized keywords in the field, a flexible approach was adopted. The literature selection process involved storing academic and industrial publications based on their titles, abstract, and full texts retrieved from electronic library systems.

To ensure a broad and credible dataset, the following online databases were used:

- Google Scholar
- Science Direct
- Thomson Reuter's Web of Science.

Additionally, Google Search Engine was used to supplement the research with industrial reports from martime companies, prot authorities, and logistics firms. These sourcs were chosen due to their extensive coverage of peer-reviewed articles, conference proceedings, and tehcnical reports.

The identified literature was systematically classified to capture key research themes and trends in DSC adoption within maritime logistics. The analysis foucused on:

- Digitaliazation trends in maritime suply chains.
- Success factors and challenges of DSC adoption
- Industry-driven vs. academic perpectives on martime digitalizaiton.

The literature review examined publication years, study objectives, and research contexts to tract the evolution of maritime DSC practices over time. Figure 1 visually represents the methodlogical approach, highlighting the key research components analyzed in the study.

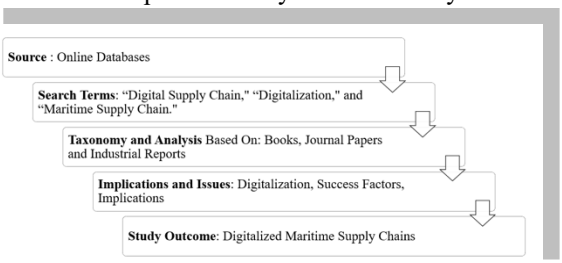

Figure 1. Review Methodology

The Systematic review provides detailed synthesis of DSC application in the maritime industry. The findings contribute to understanding how digital transformation is reshaping maritime logistics and offer practical insights for future research and industry adoption.

3 Review of Literature on Maritime DSC

3.1 Academic Literature on DSC in the Maritime Industry

The rapid innovation in information technology within the last three decades has come with the development of new software applications, systems, and standards that shape and support business activities differently. While several researchers have explored enablers in container terminals and maritime ports, studying digital supply chains from an inter-and intra-organizational perspective is essential to improve port practices, networks, and processes [8]. With competition in the maritime industry, the digitalization of supply chains has received much attention from industry practitioners. Currently, limited studies are uncovering the full potential of digital supply chains in the maritime industry. Nonetheless, some studies explicitly explore digital supply chains in other sectors regarding their applications. The analysis completed in this review

supports this statement. Existing journal articles related to digital supply chains in the maritime industry are classified in **Table 1**.

3.2 Published Books on DSC in the Maritime Industry

One of the books that explains the digital supply chain in the maritime industry was prepared by Thierry and Christa, substantiating the significant contribution of DSC in the industry, streamlining port logistics. The book also uncovers the rapid development of digitalization in the maritime sector, apparent technologies impacting the industry, and the strategic significance in maritime organizations. Another book by MacCarthy and Inavov covers the digitalization of supply chains across various industries [11]. The book also has a dedicated chapter on digitalizing the international shipping and maritime logistics industry, using a case study of Trade Lens. Uncovering the digitalization of the supply chain in the maritime industry, the book argues how digitalization varies across the shipping ecosystem, where higher levels of digitalization are apparent in the ship designs and shipbuilding using artificial intelligence and unmanned vehicles, robotics to inspect vessels and use of big data to understanding ship navigation, and advanced ports management. The book has different chapters that investigate the emerging changes in the digitalization of maritime companies, as well as consider what the future holds for this rapidly shifting and evolving field.

Another book by Notteboom, Pallis, and Rodrigue delves deeper into the specifics of the digital supply chain by arguing that Industry 4.0 and the Internet of Things have revolutionized some key aspects of the shipping industry by enabling vessel tracking, management, and better container handling [9]. The book presents an overview of digitalization, its impacts, and objectives in various sectors, detailing the concept of a digital supply chain to enhance and improve supply chain management processes. The three books find that maritime firms must have better, and integrated security processes and tools needed for digitalization.

3.3 Industrial Reports on DSC in the Maritime Industry

Industry reports have also been prepared to explore the effects of digitalization from an industrial perspective, addressing the dynamics of the shipping industry. One of the reports by the World Bank-IAPH explained the role of maritime transport as the backbone of the global economy. Collecting data and evidence from different companies, the report argues that digital technology can minimize the need for human interactions, helping protect the sector against future shocks. Another report by ABI Research contends that the strategic role of the shipping industry, digital transformation, can trigger wide-ranging economic benefits and contribute to a sustainable and more substantial recovery, especially in low and middle-income countries. By explaining the role of blockchain technology as another significant component of supply chain digital transformation, the report argues that blockchain can be leveraged to track the provenance of goods, ensuring compliance and authenticity. In the maritime sector, the IoT sensors effectively monitor the humidity and temperature of cargo containers, ensuring that perishable goods are preserved within optimal conditions, and the authors have expressed significant improvements in digitalization in the maritime industry.

Maritime Fairtrade made a report showing blockchain adoption in the maritime supply chain. With more than 90 percent of the world's goods depending on the maritime industry for transport, the digitalization of the maritime supply chain and logistics is significant. The real-world utility of blockchain technologies is apparent across countries. The report argues that although classical maritime logistics contribute to poor end-to-end supply chain integration, digitalization of shipping operations advances new and innovative business models capable of generating real value across the global value chain. The report also provides a DSC implementation roadmap to help industry leaders, supply chain managers, and other specialists interested in developing supply chains to transform supply chain organizations by focusing on the customers, lowering supply chain costs, and boosting revenues.

3.4 Advantages, weaknesses, and limitations of DSC in maritime supply chain literature

This section thoroughly examines the advantages, weaknesses, and limitations of the digital supply chains in the maritime industry to understand the industry better.

Table 1: Summary of Key Literature on Digital Supply Chains in the Maritime Industry

References	Subject	Objective	Method	Contribution
Choi et al. [1]	ERP	Explore how to develop ERP systems for container terminals to boost software quality.	Review	This paper contributes by presenting an approach that can promote the adoption of information systems to boost container terminal supply chains.
Raza et al. [2]	Digital Transformation	This paper explores the digital maturity levels, opportunities provided by digitalization, and the challenges hindering digitalization in the maritime	Survey	This paper contributes to a better understanding of maritime digital technologies' implementation and challenges.

		logistics industry.		
Surucu-Balci, Iris & Balci [3]	Digital Information Systems	This paper seeks to uncover digital information systems' dynamic capabilities, enablers, barriers, and outcomes in maritime supply chains.	Systematic literature review	This paper provides a holistic approach to improving the understanding of digital information systems in maritime supply chains.
Balci & Surucu-Balci [4]	Blockchain	This paper aims to investigate the relationship between blockchain adoption barriers.	Modelling	This paper contributes by uncovering theory and practice using a stakeholder theory perspective to understand digital information systems.
Hvolby et al. [5]	Information exchange and blockchain	This paper aims to describe the challenges of the maritime supply chain and discusses the new digital initiatives to enhance supply chains.	Case study	This paper contributes by explaining information exchange in the maritime industry, using TradeLens and Mersk as focus companies.
Kapkaeva et al. [6]	Digital information systems	This paper aims to provide a modern informational perspective of port operations and seeks to bridge the gap between scientific work and industry solutions.	Case study	This paper explains how maritime industry information systems satisfy different stakeholders' needs.
Ichimura et al. [7]	Digitalization	This paper aims to identify the impact of digitalization on the supply chain.	Literature Review	This paper explains digital technologies' characteristics and effectiveness in cost-efficiency, raising competitiveness, and meeting stakeholder needs.
Heilig et al. [8]	Digital transformation	This paper aims to evaluate modern seaport digital transformations to ascertain current potentials and barriers.	Modelling	This paper explains the impact of digital transformation in seaports.
Notteboom et al. [9]	Port management	This book aims to comprehensively analyze the modern port industry, presenting how ports are systematized to serve the global economy.	Analysis	This book analyzes the present-day port industry and port organization to serve the international economy and local growth needs.
Vanelslander & Sys [10]	Supply chain digitalization	This book aims to analyze the most regularly encountered difficulties in maritime supply chains hindering the move toward the network.	Analysis	This book offers solutions to recurrently encountered complications and key operational issues; it also applies systematic pioneering methods to the maritime supply chain.
MacCarthy & Ivanov [11]	Supply chain digitalization	This book explains the digital supply chain and explores the comprehensive effect of digitalization across various industries.	Analysis	The book provides the indispensable foundation for further examination, analysis, and appraisal of the Digital Supply Chain.
Bavassano et al. [12]	Blockchain	This article aims to provide insights that might help the shipping industry to deal with the ultimate technological leap.	Triangulation	This article is essential in defining how blockchain technology can be implemented in the shipping industry and defining significant effects and barriers to developing such technology.
Yang [13]	Blockchain	This paper aims to explore the effectiveness of blockchain applications and future improvements in maritime supply chains.	Survey	This article gives insights into maritime shipping blockchain-based digitalization and points out the future direction of developments in blockchain technology.
Sys et al. [14]	Maritime digital technologies	This paper aims to explain the different innovative technologies in the maritime supply chain.	Analysis	The article contributes by explaining how various technologies are effectively used in the maritime supply chain.
Carlan et al. [15]	Digital Innovation	This paper aims to identify the best practices and lessons cultured from examining the selected cases.	Case study	This paper explains how to upsurge responsiveness of the importance of digital technologies for enhanced supply chain performance.
Acciaro et al. [16]	Digital innovation	This article aims to explore innovations in seaport terminals and assess their success.	Analysis	This article contributes by providing a deeper understanding of innovations in seaport terminals.
Ahmad et al. [17]	Blockchain	This article discusses the potential role of blockchain technology in changing port logistic operations and services.	Modelling	This article discusses how seaport companies can use blockchain technology to transform port logistics, operations, and services.
Ho & Hsu [18]	Blockchain	This paper explores vital influencing factors affecting the application of blockchain expertise from the perspective of Taiwan shipping companies.	Survey	This article analyzes key factors influencing blockchain technology integration into shipping companies.
Liu et al. [19]	Blockchain	This paper aims to assess how blockchain technology is used in maritime supply chains, the applications, architecture, and challenges.	Comprehensive literature review	This article contributes by providing a deeper outlook into ways to fast-track the blockchain application in the maritime industry.
Hu et al. [20]	Digital technologies	This book aims to explore how different information technologies can be used to understand supply chain logistics.	Analysis	This book is integral to exploring different technologies that can enhance supply chain effectiveness.
Parola et al. [21]	Digital technologies	This paper explores how adopting evolving digital technologies can offer valuable business prospects for logistics centres in maritime supply chains.	Systematic literature review	This article provides a closer look into the framework that can evaluate the effect of digital technologies on transport and maritime logistics.
Rocco Agrifoglio et al. [22]	Digital technologies	This paper investigates how emerging digital technologies affect operations management through value co-creation in the maritime industry.	Case study	This paper contributes to extant literature about the relationship between emerging digital technologies and OM by stressing the value co-creation issue.
Orji et al. [23]	Blockchain	This paper aims to appraise the factors that impact blockchain implementation in the freight logistics industry.	Analysis	This paper contributes by providing an understanding of factors influencing the adoption of blockchain to improve organizational

				competitiveness.
Acciaro & Sys [24]	Digital innovation	This paper aims to identify specific patterns in how the innovation approach impacts the degree of success in innovation execution and whether there are substantial variances among innovations.	Modelling	This paper contributes by offering a way to explore innovation in the shipping industry, explore innovation processes and increase success rates.
Lai et al. [25]	Information Sharing	This paper aims to survey the motivations for forecasting information sharing from the port and the outcome of carriers' risk behavior on such sustainability investment choices in a maritime supply chain.	Modelling	This paper contributes by providing a deeper understanding of information sharing in the maritime supply chain to boost sustainability.
Lambourdiere & Corbin et al. [26]	Blockchain	The paper aims to recommend a theory for how employing digitalization in the form of blockchain technology can expand the proficiency and success of maritime supply chains.	Literature Review	This article contributes by analyzing blockchain technologies and dynamic capabilities in supply chain performance.
Orji et al. [27]	Digitalization	This paper aims to examine the connection between awareness and fulfillment on just executed digital products and overall customer loyalty in container shipping.	Survey	This paper contributes by providing insight into key hypothetical and executive consequences regarding digitalization in container shipping and other non-tech industries.
Lind et al. [28]	Maritime informatics	This paper aims to explore how maritime informatics may empower decision-making pursued among involved actors.	Analysis	This paper contributes by exploring how maritime informatics can influence the global transport chain.
Heilig et al. [29]	Digital transformation	This paper aims to conduct a widespread analysis of digital transformations in seaports.	Analysis	This paper contributes by explaining how different levels and generations of digital transformation are in the maritime industry.
McGinley et al. [30]	Intelligent transport systems	This paper aims to inspect how different ports have integrated intelligent transport systems.	Case study	This paper contributes by thoroughly evaluating intelligent transport systems and their effectiveness in different seaports.
Zeng et al. [31]	Digitalization	This paper aims to investigate the adoption of information systems and technologies in the maritime shipping supply chain.	Case study	This paper contributes by providing broader insights into how to adopt an open platform to facilitate container bookings in the maritime supply chain.
Jiang et al. [32]	Digitalization	This paper aims to explore the impact of port-centric information integration on the performance of ports.	Case study	This paper contributes by identifying pathways to enhance port digitalization to achieve a competitive advantage.

this review, 32 articles were selected, providing insights into the digital supply chain in the maritime industry, and the results are presented in Table 1 below. The assessment in this section also identifies the gaps in the sources, correlating the findings to find future trends, synthesize past knowledge, and ascertain standard features among the selected studies. In the table, the first column explains the author's name(s), followed by the subject, the methodology that explains the data collection process followed in the selected article or book, and the contribution to understanding the digital supply chain in the maritime industry. Books, articles, and industrial reports have been analysed and synthesized based on their relevance and depth of information.

Analysing their content helped to identify gaps. After thoroughly examining and exploring the relevant studies and literature on digital supply chains in the maritime industry, they present several advantages. First, the selected sources illuminate the various applications of digitalization of supply chains in the maritime industry, followed by an exploration of different technologies used in the industry. The sources provide a roadmap for companies in the industry to integrate digitalization into

their operations. On the other hand, there are different perspectives on digitalization and supply chain management in the maritime sector. The authors, researchers, and practitioners have approached digital supply chains in the maritime sector from different perspectives, and the analysis reveals that there is a unanimously adopted definition of digital supply chains in the industry. The diverse perspectives create a challenge to understanding digitalization in the industry. The following sections will identify the key outcomes and findings from the studies, answer the main research questions, and provide a framework/roadmap for practically implementing digital supply chains in the maritime industry.

4 Digital Supply Chain Practices in the Maritime Industry

The digital revolution in the past few years is among the key drivers of change in the port and maritime sector. The integration of devices, agents, and activities has paved the way for connectivity in the industry. In the Fourth Industrial Revolution context, digital technologies, including the Internet of Things, blockchain, 3D Printing, robotics, artificial intelligence and unmanned vehicles, are changing production and supply chains [1]. With globalization and evolving production, maritime logistics have continued to become the backbone of global supply chains [5, 7]. The supply chains covered in this review consist of maritime transportation, other activities, and actors enabling cargo movement. Digital supply chain

technologies have different contributions to the maritime industry. These are shown in **Figure 1**.

From a supply chain standpoint, the maritime industry has been inefficiently linked to the end-to-end supply chain. Most businesses in the maritime ecosystem are adapted to independent operations, and they rarely interact. Without vertical and horizontal incorporation of digital keys in the industry, there is a gap in implementing digital supply chains. Research by [2] argues that the shipping sector, a core part of the maritime industry, has not yet practiced digital revolution that permeates information sharing to lower operating costs and improve efficiencies. Their research addressed the importance of digital revolution that allows stakeholders to control data access and meet the level of information sharing the industry requires [8, 15]. Most shipping methods are paper based, often involving several parties and extensive authentication methods, impacting the shipping costs [10]. This shows that digitalization has been announced at a measured rate compared to other industries.

Additionally, the maritime industry lacks ideals for shipping data shared across the supply chain, resulting in data becoming scattered across different systems. Therefore, there is a lack of proper visibility across the shipping processes, resulting in inefficient supply chain management. These issues also lead to higher costs of delays, poor customer service, and failure to meet delivery requirements. These are among the pain points that digitalization of the maritime supply chain seeks to address. The maritime industry has been faced with fraud, particularly in customs clearance procedures. It has also been impacted by several cyber-attacks that have affected several companies, raising concerns related to digital technologies and the security of shipping data. The advent of blockchain is providing an opportunity to address such issues.

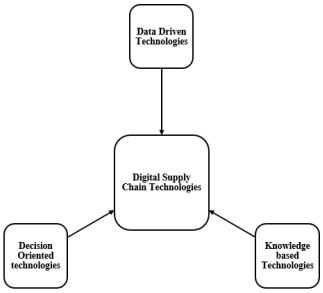

Figure 1. Digital Supply Chain Technologies

According to Gartner, digitalization is "*the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business*." In the maritime industry, digitalization differs across the shipping ecosystem, where higher levels of digitalization are apparent in ship design and shipbuilding with the implementation of unmanned vehicles and artificial intelligence, the use of robots for inspecting vessels, and advanced port management. Internet of Things (IoT) and Industry 4.0 have also been fundamental to the industry, allowing improved container and vessel tracking and management [18].

Digitalization and information and communication technologies are critical to promoting collaboration in the industry. According to reports by the World Economic Forum and Accenture, there are several themes supporting digitalization in the maritime and logistics industry: {1} digital information services where data services, including analytics and control towers, lower operating costs and enhance efficiency; {2} digital logistics services allowing the developing of cross-border platforms for data sharing; {3} Digital delivery enhancements creating more options for deliveries; {4} shared logistics capabilities including transport and warehousing.

According to [8], digitalization in the maritime supply chain is critical as it enhances operating efficiency. In this perception, digital technologies support maritime firms in improving asset utilization and allocating physical resources [14]. Many studies have reported that adopting digitalization in maritime supply chains improves operating efficiency in handling cargo and maintaining safety and security. This was supported by findings from [12], which claimed that digitalization in the maritime supply chain helps reduce inventory and labour costs by automating warehouses. Moreover, [15] finds that automation drastically reduces the costs of container terminals, improving overall efficiency.

[17] and [18] argue that digital technologies are projected to create broader and more entrenched stakeholder groups in the maritime supply chain. In this case, innovations and emerging technologies may expand shipping and receiving cargo handling [21]. From the perspective of [27], emerging digital technologies are introducing ways of overcoming vertical silos and integrating new systems to encourage stakeholder collaboration and promote innovative value propositions [11]. Digital technologies also allow clients to control freight status, refining their pleasure with the services offered [15]. These benefits are crucial for maritime supply chains since digital information exchange can fast-track logistics and transport operations.

4.1 Automation and Innovation

The port and logistics sector has been employing technologies and digital transformation tactics, streamlining their supply chains. Some digital technologies are germane and affect key parts of maritime supply chains, especially transport logistics.

Robotics: These encompass using robots to handle container equipment, including automated ship-to-shore cranes and mooring systems. With computerized ship-to-shore cranes, more than 90 per cent of tasks are automated, with an operator guiding the final drive of the spread from a remote-control room. Container ports using this technology have also combined computerization into decision-based elements and robotics-based automation within the terminal, making terminal operations smoother. In the maritime digital supply chain framework, robotics have also been used to facilitate the movement of goods and containers. Robotics are programmed machines that support or replace human work. These robots are used in various sectors in the maritime supply chains, including manufacturing, inventory management, and transport. These functions are critical to ensuring seamless movement and port operations. [14] claims that maritime robotics are used in facility management, checking defect status, and completing underwater tasks on behalf of workers. These robots are, therefore, significant in improving the functionality of ports, promoting safety, and reducing bottlenecks in the supply chain.

Process automation encompasses leveraging technology to systematize external courses for handling cargo. They include gate processes where hardware and software are combined to lessen human participation using selection systems, container and vehicle identification detection, radiation scanning, driver identification, and routing within the terminal. Process automation also ensures gate systems where radio frequency identification (RFID) and Optical Character Recognition (OCR) automate equipment tracking, clearance, and inspection. The movement of operators in terminals is also inspected using automated controls.

Decision-Making Automation: This form of automation and supply chain digitalization involves using technology to govern and optimize decisions on yard planning, stowage, container placement, and equipment and vehicle scheduling. It uses intelligent terminal operating systems (TOS) technology to monitor asset utilization, augment scheduling, and handle administrative tasks. The leading technologies used in digital transformation in maritime logistics and ports are shown in **Figure 2**.

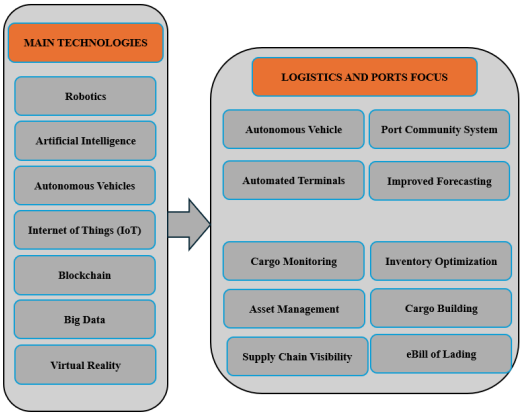

Figure 2. Digital technologies in the maritime supply chain

4.2 Automation and Robotics

Automation can be executed at the maritime digital supply chain management's infrastructure, mobile assets, and processes. Process Automation is integral in transforming logistics service providers. For instance, digitalization can integrate pricing dynamically, influence bookings and schedules, and enhance shipment visibility in real-time with marketplaces, carriers, and customers. Shipment visibility and rate automation are vital for online sales, creating new prospects for service providers since automated tools enable more profound incorporation with logistics companies, further facilitating asset allocation optimization and shipment.

According to [11], asset and organization mechanization and using robots are standard in the maritime industry. For instance, automated assembling structures in warehouses have prevailed since the 1990s. The world's first container terminal using automated stacking cranes and automated guided vehicles (AGV) was introduced in 1990 in Rotterdam. Influenced by efficiency and cost control, automation in terminals and shipping warehouses has developed over the years, but the extent ranges from remotely controlled to fully automated operations.

Since the 2010s, automation has transcended terminals and warehouses, where maritime companies can abundantly control the working conditions for automated vehicle equipment. However, while using automation, research finds that automated vehicles are impacted by issues beyond

the controlled environment, including traffic, weather, and topological conditions. Consequently, using computerized vehicles in the public domain necessitates regulatory and legislative actions. As maritime companies look forward to streamlining their supply chains, developing automated robots will require assessing the threats they impose and the opportunities in an evolving industry.

In the maritime supply chain, automation has allowed for the development of driverless trucks. Since independent trucks will be used to carry drivers in the future, advanced levels of autonomous driving are imminent. The direct influence on port operations and logistics will likely consist of improved efficiency owing to synchronized timing, better planning, and improved port and terminal efficiency. Similarly, drones are being used for inventory management and safety surveillance in some ports and warehouses. In the future, they could also monitor other logistics and detect maintenance issues. Key barriers to using drones are the regulations.

The studies argued that intelligent autonomous vehicles are a new wave of digitalization in the supply chain [20]. This technology presents a new wave of cargo handling technology designed to enhance port efficiency. According to [15] and [14], intelligent autonomous vehicles are technologically superior and are operated more economically. It does not follow selected routes entrenched in the infrastructure to reach the destination. [5] finds that autonomous vehicles are also equipped with sensors, allowing them to benefit from the Geographical Positioning System (GPS), efficiently move unmanned around port terminals, and deliver cargoes and containers to and from marshalling zones.

4.3 The Internet of Things (IoT) and Big Data Analytics

The IoT relates to physical objects linked to a network, which can receive and send data. This implies that all such items are trackable, and any action the item is used to accomplish can be measured and monitored. The IoT is rapidly evolving and is currently happening across various industries. In the maritime industry, having a network of communicating units opens up possibilities for logistics. For instance, having sensor-driven equipment will increase the connection of all assets, robotized vehicles, port equipment, and infrastructure. This leads to massive amounts of data being available for analysis and production, providing opportunities for port operators, logistics, and shareholders to automate and optimize methods and gather real-time data and insights to enhance supply chains.

According to [24], IoT has emerged as an innovative way to improve flexibility and scalability in maritime supply chains. Research by [25] found that IoT ensure certain operational flexibility, constituting a valuable competitive advantage for maritime logistics. From this perspective, digital technologies allow for managing large data volumes, increasing the scalability and adaptability of services [22]. Other papers have investigated the innovative solutions brought about by IoT [28], and they find that exploiting new technologies stimulates B2B relationships and eases the relationships and social connections across maritime supply chain by effectively using digital platforms and technologies. Many studies reported that the main strength of IoT applications is the high influence on several aspects of maritime supply chains by influencing automation [24]. [21] stated that IoT is an extension of the internet, which allows linking things, including sensors and other innovations to access data and provide seamless services.

Robust communication systems are needed to implement apps built on the IoT effectively. Ports with equipment and containers prying with signals and warehouses with scattered signals are among the leading barriers to effectively using IoT in maritime logistics. Even though there are ports and warehouses with network infrastructure, some are not appropriate to meet IoT requirements of secure protocols and high bandwidth. Nonetheless, with the evolution of IoT and digitalization taking root in the industry, big data will continue creating prospects for maritime supply chains to become data-centric and improve the value proposition of maritime logistics.

4.4 Virtual Reality and Simulation

Big data applications allow maritime supply chains to exploit simulation software's benefits fully. Port operators can model operations to investigate operational flows, assess conceivable barriers, describe supply chain boosts, and stimulate different designs for seamless logistics. This can be done for existing supply chains or new networks. Simulation software is also advantageous since it can be used to train staff in a realistic environment and allow for the simulation of different events. Virtual reality (VR) is considered to expand physical reality by adding layers of computer-generated information to the real environment. This will also support supply chain simulations. In a digitalized supply chain and logistics environment, it is possible to envision enhanced feeds from automated vehicles, equipment,

infrastructure, and drones [11]. It is projected that virtual reality will continue influencing supply chains in the maritime industry, positively impacting the execution of specific processes to streamline operations.

Virtual prototyping and operational planning are another significant use of VR and simulation in maritime supply chains. Shipbuilders and logistics companies use VR to simulate vessel designs and test different operational scenarios before implementing them in real life. For instance, digital twins' virtual replicas of ships and ports allow stakeholders to assess fuel efficiency, cargo loading strategies, and maintenance schedules in a risk-free environment [10]. This helps optimize supply chain routes, improve fleet management, and reduce unnecessary costs. Additionally, VR-assisted remote monitoring systems enable ship operators and port authorities to oversee cargo movements and port operations in real-time, minimizing disruptions and enhancing supply chain visibility.

4.5 Blockchain

Blockchain is a technology that promises to revolutionize the shipping industry. Blockchain operates as a distributed ledger shared in a peer-to-peer network containing an immutable digital record of timestamped transactions stored chronologically. Each block has an identifying cryptographic key (i.e., hash) and points back to the block that preceded it in the network [19, 23]. Blockchain has embedded security and transparency in its network, providing great potential to handle the imminent challenges in the maritime industry. A recent industry survey report shows how logistics managers adopt blockchain for supply chain management. The unique data structure system of the blockchain can help lower inventory and transaction costs [26], eliminate bottlenecks in the supply chain [27], establish a supply chain that can adapt to changes in the global economic environment [2], and track product origin [29].

Many studies reported that blockchain is also an essential part of the maritime supply chain since it allows for end-to-end visibility across the supply chain [23, 19]. Their research found that there are different areas where blockchain is applied in the maritime industry. These include managing shipping operations and cargo movement, maritime transactions without intermediaries, facilitating marine insurance by ensuring that records have timestamps, and ensuring that ship registers have immutable, traceable, and valid registers. Research by [20] finds that blockchain technology has several advantages for the maritime industry, including saving time and costs by eliminating intermediaries, allowing for intelligent transportation by providing accurate data about vessels' speed and location and optimizing travel routes [1]. However, despite these advantages, blockchain technology, most research discusses its application on a high level. Very little research has investigated the implications of adopting technology on the maritime ecosystem. There is a need for empirical research that offers insights into different aspects of blockchain in the maritime supply chain. Several blockchain-based solutions in the maritime industry include TradeLens, CargoX, and Insurawave. The analyzed literature lacks deep exploration into the state-of-the-art blockchain application in specialized tasks in maritime logistics [19].

Consequently, scholars have explored numerous review studies to understand different research issues associated with using blockchain in the supply chain management system. For instance, [23] performed a systematic literature review to identify, analyze, and classify literature surrounding supply chains. Other researchers have claimed that blockchain technology is still in its infancy. Technology's value in the digital supply chain system is in enhancing visibility through traceability, data access, supply chain digitalization, and data security.

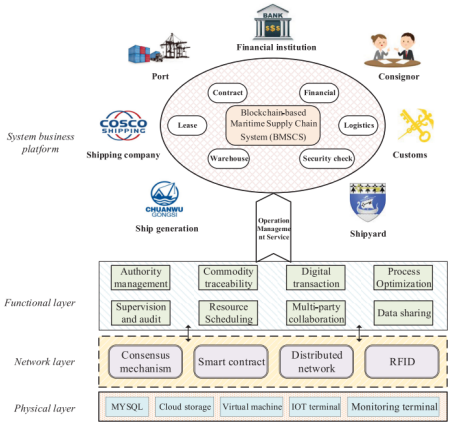

Figure 3: Blockchain-based maritime supply chain system (BMSCS) (Adopted from Jiaguo Liu, Huimin Zhang & Lu Zhen, 2021)

4.6 Cloud Computing

Cloud computing is another innovative technology solution being used in the maritime industry. According to [20], cloud computing provides resources used by supply

chains in the industry to interconnect. With scalability and resourcefulness, cloud computing guarantees seamless information flow and data sharing. In maritime supply chains, cloud computing has been integral as a data-sharing hub platform, ensuring that data shared with stakeholders is reliable and transparent. It can be replicated to improve service delivery. More importantly, [22, 21] argues that cloud computing is integral for smart port sharing and supply chain collaboration platforms. Additionally, cloud computing offers supply chains the ability to have a common platform to manage resources, reduce operating costs, and improve operational efficiency. With the help of this technology, maritime operators are provided with means to collect and analyse data with the help of IaaS, SaaS, and PaaS service models.

Cloud computing resources and resources are primarily available 'on-demand', integrating a pay-per-use model and an infrastructure-as-a-service model offering foundational computing resources, including networks, storage, and data centres. Platform-as-a-service offers a programming and applications environment, while software-as-a-service provides businesses with deployable software applications. In the maritime supply chain, cloud computing's advantages range from easier access to computer resources that are configurable and scaled to meet business needs and remotely accessed [5]. By lowering the resources needed by maritime companies, cloud computing helps stakeholders in the industry to foster digital innovation, experimentation, and collaboration, leading to evolved supply chains. Cloud architecture also provides a new technological landscape for corporate computing, with new data storage mechanisms, file management, and programming. In the supply chain, cloud computing can be used to develop advanced services, including remote equipment monitoring [11]. Clients and cloud service providers may interact with different cloud models to leverage security and supply chain efficiency.

4.7 Artificial Intelligence

Artificial intelligence introduces a logical way of thinking, learning, and judging using computers. According to [16], AI has evolved as a revolutionary technology that has changed multiple industries, positively influencing how they manage production and service delivery. Artificial intelligence is an effective technology in the supply chain, especially in maritime logistics, where it is used for navigation, finding the best routes, and providing navigation recommendations. Artificial intelligence is based on deep learning and machine learning. In the maritime supply chain, it is vital as a decision-making support system based on a predictive behavior model [12]. One of the main applications of AI is predictive maintenance, where sensors collect real-time data on ship machinery, fuel consumption, and engine performance. AI analyzes this data to predict potential failures before they occur, allowing for proactive maintenance. Other critical applications are route optimization and navigation. AI-powered systems assess historical data, weather conditions, and ocean currents to determine the most efficient shipping routes. AI also plays a significant role in cargo and inventory management by automating container tracking, optimizing space utilization, and improving demand forecasting. AI-driven analytics can predict cargo volumes, helping shipping companies and port operators efficiently manage their resources [12]. The development of autonomous ships and smart ports is another area where AI is making a significant impact. AI enables semi-autonomous or fully autonomous vessels, reducing reliance on human intervention in navigation. Finally, supply chain visibility and decision-making are greatly enhanced with AI integration. AI-powered IoT devices and cloud platforms provide real-time tracking and end-to-end visibility of shipments [18]. AI analytics assist in demand planning, supplier management, and cost control, ensuring seamless operations. AI is revolutionizing the maritime supply chain by increasing automation, reducing risks, and optimizing resources.

5 Discussion and Conclusion

The digitalization process enabled by technologies such as blockchain, cloud computing, artificial intelligence, and robotics can impact the operations of shipping companies by providing a secure digital platform that optimizes lengthy, laborious, and expensive shipping processes. Integrating these technologies can also be effective for securely tracking and monitoring containers and vessels [11]. Supply chain digitalization enabled by blockchain and cloud computing can impact maritime supply chains by enabling secure document sharing, from which ocean carriers can share sensitive documents in real-time with all relevant stakeholders, resulting in high cost and time savings. Digitalization can also allow for secure container and vessel tracking, resulting in better route optimization and container management [9].

Additionally, [7] finds that digitalization in the maritime sector is vital for offering a verifiable way of submitting necessary information, including cargo weight, to relevant authorities. All these benefits support maritime companies in enhancing their internal operating competencies and distributing optimal customer services. Nonetheless, for these benefits to be realized, companies in the industry must make significant fluctuations to their internal processes to pave the way for digitalization alongside developing new business models.

Digitalizing the shipping processes is critical for improved efficiencies, information sharing, and reduced costs. For

example, [7] argues that blockchain-based solutions are significant for end-to-end traceability and visibility across the supply chain. This results in upgraded supply chain scheduling and organization at the supply chain level, allowing maritime companies to respond better to supply chain disruptions and risks [2]. Digitalization is crucial for improving efficiency and reducing workload, including paperwork, for in-house supply chain logistics. TradeLens, for example, allows for automated and secure automated information and documentation. All supply chain partners are provided with the means to access cargo information, creating a rich data environment and end-to-end visibility that optimizes supply chain logistics [3]. Streamlined shipping procedures benefit maritime companies by lowering costs and lead time in handling documents and avoiding demurrages and detention.

Applying blockchain, cloud computing, robotics, and artificial intelligence in monitoring container and cargo temperature and moisture levels has also allowed maritime companies to minimize losses [13]. They are also able to ensure proper transportation of perishable and sensitive products. On a higher level, digitalization in the maritime supply chain has provided a platform for companies to directly interact and connect with the shipping ecosystem and get real-time visibility of the shipping process [4]. Therefore, digitalization is crucial for enhancing information sharing, benchmarking, and performance measurement in the maritime industry. Additionally, the digitalization of trade documents significantly impacts the shipping processes, including the roles played by authorities. [12] argues that this has been perceived as vital potential area of blockchain application in the maritime industry. Digitalization has the potential to transform customs procedures to become more data-driven and deeply embedded within the shipping process to provide an immutable and secure record of documents and shipping transactions in real time between all maritime stakeholders [2,12]. The automation and digitalization process is crucial in helping to reduce errors and manage administrative work. The impact of digitalization on the supply chain customs procedures relies on how digitalized regulators and customs authorities are related to using digital documents.

Ports and terminals are also crucial in integrating maritime supply chain logistics. Despite the digitalization level, there remains a significant amount of paperwork in ports and terminals. Digitalizing the workflow and using automated technologies for exchanging documents enable timely access to essential data, a crucial success factor in ports and terminals [8, 17]. Digitalization thus provides better visibility for terminal and port operators across multiple transporters, providing data for supply chain management.

To advance performance in an evolving environment, maritime companies must learn how to develop a ultimate ability of supply chain organization. This pertains to the capacity to complement their logistics with stakeholders. To optimize the maritime industry's digital supply chain, coordination helps develop synchronized and seamless supply chains [28]. Such a strategy is critical to reducing operating costs and lead time, improving supply chain flexibility, and increasing operational efficiency to cope with rising uncertainty in demand. Digitalization has evolved as the key driver of supply chain management and coordination, with maritime supply-chain stakeholders capitalizing on digitalized logistics to enhance process coordination [29]. However, addressing the issues connecting data-based methods across supply chains is necessary.

Even though implementing digitalization in the maritime sector can result in more efficient interoperability, digitalization can also require heavy investment costs. Nonetheless, digital technologies such as blockchain and IoT provide flexibility and security at lower costs than traditional technologies, allowing cost-effective measures to be embedded in maritime operations using decentralized systems [28]. Additionally, digitalization in the maritime supply chain processes can address restrictions and promote organization of processes and stakeholders [14].

In their long-term digitalization strategies, maritime firms must adopt technologies aligning with their supply chains. To do this, maritime companies can choose a conservative strategy where information systems can be used to expand operational productivity and information exchange among stakeholders. Such a strategy would be achieved using electronic data exchange, workflow automation, and transaction processing systems. Another strategy is using information systems to improve the effectiveness and agility of maritime companies. This approach would be categorized by using a collection that supports novelty and creates new market prospects [16]. Using these two strategies, maritime companies can achieve comprehensiveness with digitalization, creating more visibility in their supply chains.

For maritime companies to optimize their supply chains, digitalization would improve transparency by offering a comprehensive interpretation of the whole supply chain. High prominence signifies that real-time processes and responses can be integrated into the scheduling and implementation levels. With digitalization, supply chain flows can be tracked in real time [19]. Implementing digitalization can help maritime companies achieve their operating objectives by increasing supply chain visibility, accountability, and transparency. The technology can be optimized to help maritime companies identify fake products, enable origin sketching, and improve transport logistics management.

Along the supply chain, various challenges and problems could occur, impacting the process of gathering data and ensuring that the data is accurate to represent the effectiveness. While implementing a digital supply chain

in the maritime industry, several considerations must be made, including the length of the chain, the inventory and logistics infrastructure, stakeholder needs and expectations, and the operating environment [22]. Due to the high data security, auditability, privacy, and immutability of digital technologies in the maritime supply chain, the maritime industry has a huge potential to automate port terminals. Different digital supply chain technologies' explicit features are critical for improving stakeholders' trust in port logistics operations. Nonetheless, technologies such as blockchain and their adaptability in the maritime industry still face challenges mainly related to the companies interested in investing in the high costs of deploying blockchain and the lack of regulations for blockchain technology management [25]. The complexity of maritime digital supply chain technologies creates a decentralized network, making it challenging for individual companies to comprehend, accept, and integrate digital technologies with confidence.

This research aimed to provide actionable insights for academics and practitioners in optimizing digital practices to enhance operational efficiency, resilience, and service reliability using maritime digital supply chains. The research has achieved this objective, and the examined sources show that regarding technologies such as blockchain. Adopting digitalization in the maritime industry has paved the way for modernization. This study has explored digitalization in maritime companies, showing the various technologies and their effectiveness.

Additional research is necessary to explore the impact of evolving digital technologies on the effectiveness, safety, and environmental sustainability of the shipping sector and maritime industry. While the maritime sector is acknowledged as essential for future sustainable global economic growth, it continues to exhibit a low adoption of new digital technologies that facilitate information sharing, enhance efficiency, and improve safety. Additionally, extra research should emphasize the role of co-creation in defining customized on-board products and services within the maritime industry.

Compared to other sectors, the maritime industry is distinguished by significant investments in new technologies, such as onboard control and monitoring systems for ships, yachts, and vessels. In contrast, the small boat segment is not considered lucrative. Operators have noted that small boats are more prevalent and susceptible to accidents than larger vessels. Therefore, academicians must focus on the relationship between emerging digital technologies, including IoT and cloud computing, and co-creation initiatives, such as user involvement in software design, as a practical approach for mechanizing onboard operations and minimizing accident risks.

Future research should focus on exploring uniform standards on a global scale. In the digital age, it is crucial to learn how to fully use artificial intelligence, big data, cloud computing, and other new-generation information technologies to improve the international competitiveness of maritime companies. Future research should focus on developing advanced AI-driven IoT systems to provide real-time tracking and predictive analytics for cargo, fleet, and port operations. Studies could examine how this digitalization can boost efficiency, condense operational costs, and improve policymaking in maritime logistics.

Additional research should address how developing digital technologies in the maritime supply chain advances the industry's effectiveness, safety, and environmental sustainability. Experts and researchers should consider the relationship between evolving digital technologies in the maritime industry, such as cloud computing, the Internet of Things, blockchain, and artificial intelligence and co-creation initiatives, including user participation in software design to reduce risks and threats connected to these technologies.

With blockchain technology still in its initial stages in the maritime supply chain, future research should examine the processes of learning and knowledge acquisition. For example, discovering the impact of cryptocurrency on the maritime supply chain and the consequences of prebuilt trust in blockchain systems. Further studies are needed to examine the implementation of blockchain technology to boost security, transparency, and productivity in maritime digital supply chains. Research should examine how blockchain can avert fraud, improve contract management, and streamline documentation processes.

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