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TRANSFORMATION IN MARITIME SUPPLY CHAINS: INNOVATIVE STRATEGIES FOR DISRUPTION MANAGEMENT

Tunca TABAKLAR[1]

ABSTRACT

This article explores the transformation of maritime supply chains, focusing on key capabilities, including technological adoption, risk management, sustainability initiatives, and collaboration in disruption management. Through an analysis of UNCTAD reports from 2019 to 2023, this study tracks the development of these capabilities in response to disruptions, notably the COVID-19 pandemic and the Suez Canal blockage. The findings highlight the critical role of digitalization, particularly the adoption of technologies such as artificial intelligence and blockchain to enhance risk management strategies and port efficiency. Simultaneously, the increasing emphasis on decarbonization and green initiatives reflects the growing integration of environmental sustainability in the maritime sector. Collaborations were found to be vital for fostering disruption management capabilities and operational stability. This research provides a comprehensive overview of how maritime supply chains have adapted to recent challenges and provides insights into the future of adaptive and sustainable maritime supply chain management.

Keywords: *Maritime Industry, Supply Chain Management, Industrial Markets, Capabilities, Comparative Analysis*

[1] Assist. Prof. Dr., İzmir Katip Çelebi University, Faculty of Economics and Administrative Sciences, Department of Business Administration, tunca.tabaklar@ikc.edu.tr, ORCID: 0000-0001-6229-9413.

DENİZCİLİK TEDARİK ZİNCİRLERİNDE DÖNÜŞÜM: KESİNTİ YÖNETİMİ İÇİN YENİLİKÇİ STRATEJİLER

ÖZ

Bu makale, denizcilik tedarik zincirlerinin kesinti yönetimi çerçevesinde, teknolojik yenilikler, sürdürülebilirlik girişimleri ve iş birliği gibi temel yetenekler üzerinden dönüşümünü incelemektedir. 2019-2023 yılları arasındaki UNCTAD raporlarının analizi ile, COVID-19 pandemisi ve Süveyş Kanalı krizi gibi küresel kesintilere yanıt olarak bu yeteneklerin nasıl geliştiği incelenmiştir. Bulgular, yapay zeka ve blok zinciri gibi teknolojilerin kullanılmasının, risk yönetim stratejilerini ve liman verimliliğini artırmada kritik bir rol oynadığını vurgulamaktadır. Karbonsuzlaştırma ve yeşil girişimler ise çevresel sürdürülebilirliğin denizcilik sektörünün kesinti yönetimi için dönüşümünü hızlandırdığı görülmektedir. Ayrıca, iş birliklerinin, kesinti yönetimi yetenekleri ve operasyonel istikrarın sağlanmasında hayati öneme sahip olduğu görülmektedir. Bu araştırma, denizcilik tedarik zincirlerinin yakın zamanda yaşanan kesintilere nasıl uyum sağladığına dair kapsamlı bir bakış sunmakta ve sürdürülebilir denizcilik tedarik zinciri yönetiminin, kesinti yönetimi çerçevesinde geleceğine ışık tutmaktadır.

Anahtar kelimeler: *Denizcilik Endüstrisi, Tedarik Zinciri Yönetimi, Endüstriyel Pazarlar, Yetenekler, Karşılaştırma Analizi*

1. INTRODUCTION

The maritime industry is a critical component of global trade, facilitating the movement of over 80% of the world's goods (Talley, 2013). As global supply chains have become increasingly interconnected and complex (McAdam and McCormack, 2001; Singh Srai and Gregory, 2008; Thun, 2010), the industry has faced mounting challenges, including geopolitical tensions, natural disasters, and global pandemics (Gunessee and Subramanian, 2020; Sodhi and Tang, 2021). Disruptions such as the COVID-19 pandemic, the Suez Canal blockage (Özkanlısoy and Akkartal, 2022), and growing climate change concerns have exposed vulnerabilities in maritime logistics, leading to widespread operational inefficiencies, delays, and economic losses (Ivanov et al. 2017; Liu et al. 2023a). These challenges have underscored the importance of building resilience into maritime supply chains, enabling them to adapt to and recover from crises effectively (Christopher and Peck, 2004; Liu et al. 2023a; Pettit et al. 2010; Ponomarov and Holcomb, 2009; Tukamuhabwa et al. 2015).

A maritime supply chain is defined as a network involving carriers, ports, and shippers, all of which are crucial for cargo movement from the

point of origin to its destination (Talley, 2014). The large number of actors involved makes maritime supply chains complex and exposes them to various risks (Vilko et al. 2019) that require effective management. The complexity of maritime supply chains and their exposure to risks causing recent disruptions can be addressed by developing capabilities.

Dynamic capabilities, which are particularly suited to rapidly changing environments, enable supply chains to sense and seize threats and opportunities while reconfiguring resources to adapt to changes (Teece, 2007). Within supply chain management, capabilities can be developed to mitigate disruptions (Craighead et al. 2007) and adapt to evolving supply chain environments (Clifford Defee and Fugate, 2010). In line with this, dynamic capabilities can drive innovations (Kindström et al. 2013; Schoemaker et al. 2018; Teece, 2020), including technological innovations (Mousavi et al. 2019; Teece, 2010), which are considered key enablers of resilience (Belhadi et al. 2024; Yu et al. 2022) in maritime supply chains. The dynamism and ability to adapt to rapidly changing environments are well-documented in the maritime industry (Lambourdiere and Corbin, 2020; Pagoropoulos et al. 2017). Digital technologies such as blockchain, the Internet of Things (IoT), and Artificial Intelligence (AI) have begun transforming the industry by enhancing real-time visibility, improving decision-making, and enabling more seamless coordination among stakeholders (Liu et al. 2023b; Raza et al. 2023; Rejeb et al. 2021). However, despite their potential benefits, the adoption of these technologies remains limited due to factors such as a lack of technical expertise, high costs, and information security concerns (Ghadge et al. 2020; Raza et al. 2023).

While technological innovation can enhance maritime supply chains against disruptions, collaboration between maritime industry stakeholders can be essential for improving resilience and ensuring smooth operations during incidents that cause disruptions in a supply chain (Chaudhuri et al. 2018; Friday et al. 2018; Li et al. 2015; Munir et al. 2020; Wiengarten et al. 2016). Supply chain integration (SCI), defined as the coordination and collaboration of activities among firms to achieve mutual goals, is particularly critical in the maritime context (Liu et al. 2018; Seo et al. 2015; Tseng et al. 2015; Yuen and Thai, 2017). Seo et al. (2015) emphasize that effective collaboration between ports, shipping lines, and inland logistics providers is essential for streamlining container movements and reducing delays during crises. However, significant barriers to collaboration remain, including a lack of trust, misaligned goals, and resistance to change, all of which inhibit supply chain integration (Duong and Chong, 2020; Luthra et al. 2022; Yuen and Thai, 2017). Overcoming these challenges is crucial to

enhancing resilience and flexibility, as seen in the COVID-19 pandemic (Gupta et al. 2022; Rogerson et al. 2024) and the 2016–2017 Gothenburg port conflict, where spatial flexibility and alternative port usage helped mitigate the impacts of disruptions (Rogerson et al. 2024).

In addition to innovation and collaboration, sustainability is another growing concern for the maritime industry (Chávez et al. 2024; Wang et al. 2023). Regulatory pressures such as global environmental initiatives are driving the sector to adopt green maritime supply chain management practices (Jasmi and Fernando, 2018). These practices include using low-emission fuels, optimizing vessel routes, and reducing marine pollution (Poulsen et al. 2016). While ports and shipping lines in developed economies have made significant strides in decarbonization, challenges persist in less developed regions, where infrastructure limitations and financial constraints hinder the adoption of green technologies (Ampah et al. 2021; Banomyong, 2005). The maritime industry's uneven progress in adopting sustainable practices calls for a more collaborative and globally coordinated approach to achieving long-term environmental goals (Arjona Aroca et al. 2020; Wang et al. 2020).

Building resilience in maritime supply chains requires a comprehensive approach that integrates innovation, collaboration, and sustainability (Chua et al. 2022; de la Peña Zarzuelo et al. 2020; Del Giudice et al. 2022; Praharsi et al. 2021; Tijan et al. 2021). Liu et al. (2023b) propose that maritime resilience strategies should focus on robustness and adaptability, enabling supply chains to anticipate, respond to, and recover from disruptions effectively. This research aims to explore how the maritime industry has responded to major disruptions between 2019 and 2023, focusing on the roles of innovation, collaboration, and sustainability in building resilience. By synthesizing insights through comparative analysis and document analysis from academic literature and publicly available reports from the United Nations Conference on Trade and Development (UNCTAD) Review of Maritime Transport reports from 2019 to 2023 as this study provides propositions for further research to improve the long-term adaptability and sustainability of maritime supply chains in addressing these years covers major disruptions that the maritime industry and supply chain management has encountered recently. Based on the comparative analysis across the reports, this study develops propositions and seeks answers for the following research questions:
1) How does maritime supply chain management respond to disruptions?
2) How does maritime supply chain management use lessons learnt from previous disruptions for future research and practice?

The remainder of the article is structured as follows: The next section synthesizes key research on maritime supply chain resilience, focusing on disruption management, technological innovations, and sustainability efforts. The methodology section outlines the research approach, which includes document analysis and comparative case studies of key disruptions. In the discussion section, the paper explores how the maritime industry has managed disruptions through innovation, collaboration, and sustainability, drawing from both theory and empirical evidence. Finally, the conclusion summarizes the findings and offers propositions for enhancing the resilience of maritime supply chains in the face of future disruptions.

2. LITERATURE REVIEW

The maritime industry is considered a fundamental pillar of global trade (Pallis, 2017) and accounts for the transport of over 80% of global goods by volume (Talley, 2013). As supply chains have grown increasingly complex, global and integrated, the role of maritime industry has evolved, shifting from a focus on basic cargo handling to a more holistic approach centered on supply chain management (Carbone and Martino, 2003). The industry is now not only concerned with the physical transportation of goods but also with the strategic coordination of logistics activities across various stakeholders, including ports, shipping lines, freight forwarders, and inland transportation providers (Banomyong, 2005).

Much of the literature on maritime supply chains has independently examined the activities of ports, shipping lines, and shippers (Talley, 2014). However, integrating these components into a cohesive maritime supply chain is crucial for enhancing efficiency, reducing logistics costs, and improving decision-making (Power, 2005). Therefore, this section synthesizes the key developments in the field of maritime supply chain management, emphasizing the management of risks, innovations and disruptions.

A maritime supply chain, as described by Talley (2014), involves carriers, ports, and shippers working together to facilitate the movement of cargo. Traditionally, ports functioned primarily as nodes facilitating the transfer of goods between sea and land transport systems (Notteboom and Rodrigue, 2005). However, as global trade has expanded, the role of ports has transformed significantly (Hall and Jacobs, 2010). Today, ports are integral to supply chain management, functioning as logistics hubs that not only handle cargo but also provide value-added services such as

warehousing, distribution, and freight consolidation (Carbone and Martino, 2003). Talley (2014) also notes that the profitability of carriers and the throughput of ports play direct and indirect roles in decisions regarding participation in specific maritime transport chains. The emergence of port-centric logistics has been a response to the increasing demand for integrated logistics solutions, where ports are actively involved in managing both material and information flows across the supply chain (Bichou and Gray, 2004). This shift has necessitated substantial investments in infrastructure, digital technologies, and operational capabilities to support the growing complexity of maritime supply chains (Pallis, 2017).

The integration of ports into global supply chains has become a key driver of competitiveness, with ports now seen as critical enablers of efficient and reliable logistics services (Banomyong, 2005). As Carbone and Martino (2003) argue, ports are increasingly evaluated based on their ability to contribute to the overall performance of the supply chain. Furthermore, the rise of intermodal transport systems—where goods move seamlessly between sea, road, and rail—highlights the need for ports to function as central nodes in the broader logistics network (Bichou and Gray, 2004).

Effective SCI is critical for ensuring the smooth flow of goods in maritime logistics. Integration involves coordinating activities across different stakeholders—such as shipping lines, port authorities, customs, and inland transport providers—to create a seamless logistics network (Yuen and Thai, 2017). However, achieving SCI in the maritime industry is often hindered by fragmented operations, misaligned goals among stakeholders, and a lack of trust (Bichou and Gray, 2004). Banomyong (2005) highlights the importance of security in facilitating integrated supply chain operations. These initiatives emphasize the need for collaboration to ensure both security and competitiveness in global supply chains (Barnes and Oloruntoba, 2005).

Digital transformation has also emerged as an enabler of collaboration within supply chain management (Kache and Seuring, 2017). Thus, technologies such as blockchain, IoT, and real-time data-sharing platforms enhance visibility across maritime supply chains, allowing stakeholders to make informed decisions and coordinate their activities more effectively (Liu et al. 2023b). By providing accurate, real-time information on cargo movements, these technologies improve transparency and trust among stakeholders, facilitating smoother operations and reducing the risk of delays (Bichou and Gray, 2004). As

global trade becomes increasingly volatile due to disruptions caused by natural disasters, geopolitical tensions, and pandemics, managing risks and enhancing resilience have become critical priorities for maritime supply chains (Shen and Li, 2017). Maritime logistics is particularly vulnerable to disruptions because of its dependence on a complex network of actors and reliance on specific routes, such as the Suez Canal or the Panama Canal (Fan et al. 2022). The 2021 Suez Canal blockage, for example, highlighted the cascading effects that a single disruption can have on global trade flows, leading to delays, rerouting, and increased freight costs (Rogerson et al. 2024).

To manage these risks, maritime supply chains must adopt both proactive and reactive strategies. Proactive strategies involve building resilience into the supply chain through redundancy, such as maintaining multiple sourcing options, and flexibility, such as the ability to reroute vessels during disruptions (Kamalahmadi and Parast, 2017). Reactive strategies focus on minimizing the impact of disruptions once they occur, such as through efficient crisis management and contingency planning (Barnes and Oloruntoba, 2005).

2.1. Managing Disruptions in Maritime Supply Chains

Operational risks involve regular supply-demand imbalances, whereas disruption risks stem from more severe, infrequent events such as natural disasters, strikes, or geopolitical conflicts (Kleindorfer and Saad, 2005). Supply chain disruptions are often classified into two broad categories: demand-side risks and supply-side risks (Kilubi, 2016). Kleindorfer and Saad (2005) provide a conceptual framework for managing these risks, emphasizing that disruption risks require a distinct set of risk management strategies compared to operational risks. Disruptions in maritime supply chains can lead to significant losses, not only due to delays in shipping but also because of cascading effects throughout the supply network (Li et al. 2024; Nguyen et al. 2023, Wendler-Bosco and Nicholson, 2020; Wilson, 2007). For example, transportation disruptions often halt the flow of goods without directly affecting production, but their ripple effects can lead to inventory imbalances and missed delivery windows across multiple echelons of the supply chain (Wilson, 2007).

Shen and Li (2017) further emphasize the dynamic nature of supply chain disruptions, noting that both demand disruptions (e.g., sharp reductions in consumer demand) and supply disruptions (e.g., delays in manufacturing or shipping) can significantly destabilize global supply

chains. For instance, the tsunami following Tohaku Earthquake in Japan in 2011 affected the automotive industry for months, demonstrating the prolonged impact of such disruptions. In a maritime context, these disruptions can halt operations at ports, create bottlenecks in critical trade routes, and result in costly rerouting of ships (Matsuo, 2015; Park et al. 2013).

Research on disruption management identifies proactive and reactive strategies. Proactive strategies involve building resilience into the supply chain through redundancy, flexibility, and collaboration, while reactive strategies focus on minimizing the impact once a disruption occurs (Can Saglam et al. 2021; Kamalahmadi and Parast, 2017; Kırılmaz and Erol, 2017). Kamalahmadi and Parast (2017) examined various redundancy practices, such as pre-positioning inventory and engaging backup suppliers, as effective ways to mitigate the effects of supply and environmental disruptions. These strategies provide actors with alternative sources or stocks of goods to maintain supply chain continuity when primary suppliers or routes are affected. Redundancy, though effective, can introduce high costs (Chopra and Sodhi, 2004), thus Oke and Gopalakrishnan (2009) highlighted the challenge of balancing redundancy and efficiency.

In contrast to redundancy, flexibility is a cost-effective alternative that has gained significant attention in recent years. Flexibility-based countermeasures, such as the ability to reroute ships or use alternative ports, have proven effective in responding to disruptions like the Suez Canal blockage and the COVID-19 pandemic (Rogerson et al. 2024). Flexibility enables firms to quickly adapt to changing conditions, minimizing downtime and ensuring the continued flow of goods. However, as Ivanov et al. (2017) noted, flexibility requires strong collaboration across the supply chain, as it depends on the availability of multiple logistics options and timely access to information

2.2. The Role of Innovation in Disruption Management

Technological innovations play a critical role in managing disruptions by providing real-time data and enabling better decision-making (Ivanov et al. 2019; Kwak et al. 2018). The rise of digitalization in the maritime industry has improved visibility across the supply chain, allowing stakeholders to anticipate and respond to disruptions more effectively. Liu et al. (2023b) identified blockchain technology as a key innovation that enhances supply chain transparency and traceability, making it easier to identify the source of a disruption and take corrective

actions. Similarly, AI and machine learning are being used to predict potential disruptions based on historical data and environmental factors, enabling companies to take preemptive action.

However, the adoption of these technologies remains uneven across the maritime industry. Raza et al. (2023) noted that many firms, particularly in developing regions, have been slow to implement digital innovations due to high upfront costs and concerns about cybersecurity. This lag in adoption creates disparities in disruption management capabilities, as firms with advanced technologies are better positioned to withstand crises.

Collaboration and information sharing are also critical to effective disruption management (Duong and Chong, 2020). Ivanov et al. (2017) proposed that managing the ripple effect of disruptions requires seamless communication between stakeholders, including shipping lines, ports, and inland logistics providers. Digital platforms that facilitate real-time data sharing and collaborative planning, such as blockchain networks, can significantly improve supply chain resilience by ensuring that all parties have access to the same information and can coordinate their responses (Min, 2019).

Past disruptions in maritime supply chains have highlighted the need for a more holistic approach to disruption management, one that integrates both operational resilience and technological innovation (Berle et al. 2011; Lau et al. 2024; Nguyen et al. 2023; Verschuur et al. 2022). The Suez Canal blockage in 2021 and the COVID-19 pandemic demonstrated the limitations of traditional supply chain management (Liu et al. 2023c). As maritime supply chains become more interconnected and globalized, the risk of systemic failures increases, making it essential for firms to build both redundancy and flexibility into their operations (Shen and Li, 2017; Kamalahmadi and Parast, 2017).

In summary, the literature suggests that managing disruptions in maritime supply chains requires a multidimensional approach that combines proactive risk management, technological innovation, and collaborative strategies. Actors in maritime supply chains must strike a balance between maintaining operational efficiency and building the necessary capabilities to withstand future disruptions. As the maritime industry continues to evolve, the ability to adapt to both expected and unexpected crises will be a key determinant of long-term success.

3. METHODOLOGY

Based on the research questions posited, this study adopts a qualitative research design (Maxwell, 2013) to explore the evolution and development of maritime supply chain strategies from 2019 to 2023, focusing on how the industry has adapted to major disruptions through developing innovation, collaboration, and sustainability capabilities. A qualitative approach is appropriate because it allows for an in-depth understanding of complex phenomena (Flick et al. 2004) within their real-life context.

The primary data sources for this study are the United Nations Conference on Trade and Development (UNCTAD) Review of Maritime Transport reports from 2019 to 2023. Secondary data can be used as a supporting element for a case study (Yin, 2009) or another type of methodology (Bowen, 2009). Also, secondary data could be used as a standalone method as a way of exploration (Bowen, 2009; Harris, 2001). These annual reports (see Table 1) provide comprehensive and authoritative information on developments in maritime trade, fleet capacity, port traffic, regulatory changes, and technological advancements. The selection of reports from these specific years encompasses significant global events that have profoundly impacted the maritime industry, including the COVID-19 pandemic, the Suez Canal blockage, and increasing environmental concerns. Using secondary data could be advantageous for researchers as secondary data provides comprehensive sample and information (Bowen, 2009) as well as they provide a reduced bias and social desirability effect, and historical perspective over management actions (Harris, 2001).

The data collection process involved systematically reviewing each of the selected UNCTAD reports. Relevant sections related to technological adoption, risk management practices, sustainability initiatives, and collaboration efforts were identified within each report. Key information and text to the study's focus areas were extracted and organized thematically. This thematic organization facilitated the identification of patterns and shifts in industry practices across the five-year period under review.

Table 1: Data Sources

UNCTAD Report Title	Code	Number of Pages
Review of Maritime Transport 2019	RMT2019	130
Review of Maritime Transport 2020	RMT2020	148
Review of Maritime Transport 2021	RMT2021	154
Review of Maritime Transport 2022 – Navigating stormy waters	RMT2022	171
Review of Maritime Transport 2023 – Towards a green and just transition	RMT2023	182

The data analysis involved coding and thematic analysis of the extracted information from the UNCTAD reports. Patterns, themes, and categories that emerged across the reports were identified using thematic analysis techniques (Tate et al. 2010). This method is suitable as it provides a flexible and systematic way to analyze qualitative data, allowing for rich and detailed exploration. By contextualizing the data within these theoretical frameworks, the study provided a multidimensional analysis of the maritime industry's adaptation strategies. This approach allowed for a deeper understanding of the underlying mechanisms driving the industry's responses to disruptions. The review reports were compiled by a team of experts at UNCTAD with the support of other UN commissions and industry professionals, including shipping companies, port authorities, and international organizations. They are based on data collected through surveys, official statistics, and industry reports. Thus, the reports are a source of rich secondary data, which ensures trustworthiness by providing a breadth of data and expertise (Boslaugh, 2007), as well as offering information that may not be accessible through primary data collection (Cowton, 1998). This includes longitudinal data collected from a wide range of actors and sources over a 5-year time span.

4. SUMMARY OF THE KEY FINDINGS FROM THE REPORTS

The UNCTAD Review of Maritime Transport reports from 2019 to 2023 provide a comprehensive overview of the maritime industry's responses to various global challenges. These reports offer insights into the development of capabilities in the highly dynamic maritime environment. They particularly emphasize advancements in technology, evolving risk management strategies, increasing sustainability efforts, and strengthening

collaboration frameworks. Together, these elements demonstrate that maritime supply chains have the ability to adapt to changes during a period marked by significant disruptions, such as the COVID-19 pandemic and the Suez Canal blockage.

In 2019, there were only a few initiatives regarding technological adoption; however, as the years progressed, the digitalization of maritime supply chains advanced significantly. Technological advancement, in particular, accelerated during the COVID-19 pandemic, which forced the maritime industry to adopt digital tools quickly. This period also paved the way for the use of block chain and cybersecurity measures in subsequent years. Thus, from 2019 to 2023, a notable trend was the maritime industry's progressive adoption of new technologies. This transformation proved particularly crucial during the pandemic, highlighting the importance of real-time visibility and data-driven decision-making.

Alongside technological advancements, the approach to and understanding of risk management capabilities evolved substantially. Over the years, risk management strategies transitioned from being reactive to becoming more proactive, driven by disruptions like the COVID-19 pandemic and the Suez Canal blockage. In 2019, strategies were relatively static, but the pandemic served as a catalyst for change. Real-time assessment frameworks using digital platforms were introduced, alongside dynamic rerouting strategies and contingency plans to navigate disruptions. For instance, during COVID-19 lockdowns, shipping lanes were re-routed, and some carriers switched to air freight. However, rerouting as a disruption management method raised sustainability concerns. By 2023, these strategies had matured into more standardized practices, supported by enhanced digital coordination and logistics management, reducing the need for frequent rerouting.

Sustainability also emerged as a cornerstone of the industry's evolution during this period. During the 2019–2020 period, there was an introduction of greenhouse gas reduction strategies. From 2021 to 2022, the maritime industry began investing in green corridors, and sustainability goals started influencing routing and port operation decisions. These efforts intensified by 2023, with more ports and shipping companies adopting carbon reduction strategies and automating operations to align with global environmental goals. Notably, in 2023, within the framework of the European Union’s Green Deal, the Carbon Border Adjustment Mechanism became effective. This initiative aims to introduce carbon tariffs on imports of carbon-intensive products and reduce negative impacts on climate change.

Finally, collaboration became an indispensable component of the maritime industry's response to global disruptions. In 2019, collaboration initiatives were mostly limited to a regional level (within continents), with little multi-stakeholder engagement. However, the COVID-19 pandemic necessitated unprecedented levels of collaboration among various stakeholders, enabling real-time congestion tracking. As a result, collaboration became a key element of disruption management, underscoring the industry's ability to adapt to an ever-changing environment.

5. DISCUSSION

The maritime industry, as a cornerstone of global trade, has experienced significant transformation in recent years, driven by technological innovation, the need for greater resilience, and regulatory pressures. This study has analyzed how the industry has responded to disruptions between 2019 and 2023, particularly through the adoption of digital technologies, collaborative strategies, and sustainability initiatives (see Table 2 with illustrative quotations from the corresponding UNCTAD report for each year.). A review of existing literature further complements these findings, highlighting the long-standing challenges and emerging solutions that are shaping the future of maritime supply chain management.

Table 2: Development of Capabilities in the Maritime Industry (2019–2023)

Code	Technological Adoption	Risk Management & Rerouting	Sustainability & Green Initiatives	Collaboration
RMT2019	Early adoption of blockchain and IoT. Illustrative Quotation: *"Players in the shipping industry are increasingly taking advantage of digitalization and joint collaborative platforms and solutions enabled by new technologies and innovations, including blockchain, and are thus changing their business and partnership models."* (p. 83)	Awareness of the importance of risk management, limited rerouting due to trade tensions. Illustrative Quotation: *"Relevant scientific data are necessary, in particular, for monitoring and early warning systems for effective disaster risk reduction and management and effective emergency response; as well as forecasting and effective risk- and vulnerability assessment, to improve levels of preparedness and help take appropriate adaptation response measures."* (p. 91).	Sustainability initiatives became important Illustrative Quotation: *"Ports are increasingly expected to align their performance with sustainability expectations, namely, to deliver optimum economic and social gains while causing minimum environmental damage."* (p. 48)	Collaboration efforts to increase efficiency and the possibility to mitigate disruptions. Illustrative Quotation: *"In 2018 and 2019, several alliances and joint ventures were established between terminal operators, as well as between liner companies and terminal operators, to engage in the joint operation of berths."* (p. xi)

RMT2020	Accelerated digitalization due to COVID-19. Illustrative Quotation: *"Leveraging digitalization to enhance port resilience will require increased investment in technological innovations and strengthened cybersecurity to protect digital infrastructure…As many ports are lagging behind in terms of electronic commerce and data exchange, it will be necessary to boost Internet capabilities and accessibility inside and outside port areas for port workers and users alike and engage in innovative training approaches to scale up the use of and maximize benefits from technological innovations."* (p.62)	Pandemic was unexpected in terms of scale; significant rerouting during pandemic lockdowns. Illustrative Quotation: "*Suppressed demand forced container shipping companies to adopt more stringent strategies to manage capacity and reduce costs. Carriers started to significantly reduce capacity in the second quarter of 2020. Capacity management strategies such as suspending services, blanking scheduled sailings and re-routing vessels have all been used."* (p. xii) *"Risk assessment and management are common practice in business and policymaking processes, especially with the emergence of various risks – security threats, environmental risks, changing weather patterns and rising social unrest. However, it would appear that the likelihood of a disruption of the type and scale of the COVID-19 outbreak was not foreseen or it was underestimated."* (p. 19)	Climate emergency management initiatives and start of low-sulphur fuel adoption as per IMO 2020. Illustrative Quotation: "*Determined collective action in shipping can increase confidence among suppliers of future fuels that the sector is moving in this direction. UNCTAD supports the Getting to Zero Coalition and promotes efforts to achieve sustainability, helping developing countries adapt and build resilience in the light of the climate emergency."* (p. 16) *"The implementation of the sulphur regulation as of 1 January 2020 was initially considered to be relatively smooth, and compliant fuel oil was reported to be widely available. However, some difficulties have arisen as a result of the disruptions caused by the pandemic."* (p. 129)	Growth of partnerships during the pandemic. Illustrative Quotation: *"Industry collaboration on the use of autonomous drones is also continuing, including with regard to inspections and commercial drone delivery to vessels anchored in port. The use of electronic trade documentation has increased in importance, particularly in the context of the COVID-19 pandemic, and international organizations and industry bodies have issued calls for Governments to remove restrictions on the use and processing of electronic trade documents, and where possible, ease requirements for any documentation to be presented in hard copy."* (p.121)

RMT2021	Increased use of blockchain, IoT, and AI. Illustrative Quotation: *"Customs officials, port workers, and transport operators increasingly recognize the value of new technologies and digitalization, not just as a way of boosting efficiency but also for maintaining business continuity at times of disruption. Technological innovations include advanced analytics, on-board sensors, communications technology, port-call optimization, blockchains, big data, and autonomous ships and vehicles."* (p. xxiii) "*The COVID-19 pandemic was a big disruptor that has created challenges but also opportunities for the sector. Digitalization and environmental sustainability have become key pillars of the post-pandemic recovery. Industry and governments are considering opportunities that*	Extensive rerouting after Suez Canal blockage. Illustrative Quotation: *"Freight rates increased further following the March 2021 closure of the Suez Canal. The grounding of the 20,150-TEU container ship Ever Given blocked the canal, delaying ships heading for Europe, and increasing the constraints on ship and port capacity. Some voyages had to be re-routed around the Cape, adding up to 7,000 miles to the distance. "* (p. xv)	Greater focus on decarbonization efforts. Illustrative Quotation: *"The COVID-19 pandemic has increased the focus on environmental sustainability. Maritime transport is facing growing pressure to decarbonize and enable an effective energy transition – both as a transporter and user of energy."* (p. 23) *"Countries should anticipate, prepare for and adapt to climate change by fully understanding the risks, exposure, and vulnerabilities, and by building adaptive capacity across the maritime supply chain. For developing countries, including the most vulnerable groups of countries, building back better after the pandemic will mean scaling up investment and building national capacities in climate-proofing."* (p. xxiv)	Surge in collaborative frameworks. Illustrative Quotation: *"During the COVID-19 pandemic, a group of global industry associations in consultative status with the IMO representing the maritime transportation and port sectors agreed on a joint statement calling for intergovernmental collaboration to accelerate the digitalization of maritime trade and logistics."* (p. 140)

Code	Technological Adoption	Risk Management & Rerouting	Sustainability & Green Initiatives	Collaboration
	may arise from 'building back better'. " (p. 18)			
RMT2022	Enhanced digitalization integration in operations. Illustrative Quotation: *"Maritime trade itself is also being reshaped by the digitalization of transport and logistics. In the past, maritime transport has been slow to adopt digital solutions, but especially since the COVID-19 pandemic, it has been playing catch up – as new technologies such as the Internet of Things (IoT), blockchain, big data, and AI start to improve efficiency, sustainability and resilience."* (p.20)	Continued rerouting and contingency planning. Illustrative Quotation: *"In spring 2022, China's zero-COVID policy led to lockdowns in Shenzhen and Shanghai, two of its largest manufacturing and commercial centres, requiring carriers to reroute to alternate ports such as Ningbo. To fill the gaps left by the redeployment of ships to the more lucrative East-West trade lanes, Asian regional carriers launched new intra-Asia services or enhanced existing loops to provide additional calls."* (p. xxi)	Stronger focus on green ports and decarbonization. Illustrative Quotation: *"The aim is to scale up the supply of alternative fuels by strengthening low-carbon energy supply infrastructure in ports and producing decarbonized feets and establishing "green corridors."* (p. 47)	Public-private collaborations matured. Illustrative Quotation: *"By mid-2022, Dublin Port's COVID Coordination Committee, for example, had met 115 times and issued 45 communication briefings, providing important advice and regular updates."* (p.128)

Code	Technological Adoption	Risk Management & Rerouting	Sustainability & Green Initiatives	Collaboration
RMT2023	Scale adoption of digitalization increased relative to previous years. Illustrative Quotation: *"Another example is Finland, where a digital platform with smartphone applications enables ships to view the current condition at ports and just-in-time arrival. Port community systems are another example of digital solutions that facilitate maritime trade and serve as platforms to coordinate stakeholders in a port community and enable seamless information exchange."* (p. 99)	Rerouting needs reduced due to standardized systems. Illustrative Quotation: *"Ships can use speed optimization and weather-routing services to plan routes around weather forecasts. An AI-enabled fuel model, incorporating a ship's digital twin, enables ships to accurately predict fuel consumption."* (p. 74)	Continued progress in sustainability and carbon reduction. Illustrative Quotation: *"For instance, the Carbon Border Adjustments Mechanism (CBAM) is an instrument of the European Green Deal within the overall strategy to mobilize funding for all sectors related to climate change. As of 1 October 2023, the mechanism will be an import tariff on carbon-intensive goods from abroad paid by the importer when products enter the European Union."* (p. 101)	Established collaborations for sustainability and climate action. Illustrative Quotation: *"Voluntary initiatives to develop standards for ships and fuels are undertaken by industry, including in partnership with other stakeholders. These include the Poseidon Principles initiative for responsible ship finance which involves 30 banks and seeks to align ship finance portfolios with climate action and sustainability; the Sea Cargo Charter scheme for cargo owners; and the Poseidon Principles for marine insurance adopted in 2021."* (p. 65)

5.1. Technological Innovation as a Driver of Resilience

Both the literature and recent empirical findings converge on the growing importance of technological innovation in managing disruptions within maritime supply chains (Liu et al. 2023b). Digitalization has played a central role in enhancing operational efficiency and resilience (Liu et al. 2023c; Zhao et al. 2023), allowing stakeholders to monitor cargo movements in real time, predict potential disruptions, and quickly adapt to changing conditions (Liu et al. 2023b; Raza et al. 2023). The use of blockchain, IoT, and AI in maritime supply chain management has made it easier for companies to achieve transparency and visibility across the supply chain (Ivanov, 2021), which has proven critical during crises such as the COVID-19 pandemic and the Suez Canal blockage (Rogerson et al. 2024).

The literature review supports these findings by demonstrating how digital tools not only enhance efficiency but also foster greater trust and collaboration between supply chain actors. Yuen and Thai (2017) emphasize that supply chain integration, facilitated by digital platforms, is crucial for managing disruptions and improving overall supply chain performance. By creating real-time data-sharing capabilities, these technologies reduce delays and miscommunication (Hofmann et al. 2019), thereby ensuring smoother operations even during times of crisis.

However, the adoption of digital technologies remains uneven across regions and actors within the maritime industry. As both the literature and recent data suggest, while large ports and shipping companies in developed regions have invested heavily in automation and digitalization, smaller ports and firms in developing regions face barriers such as high implementation costs and cybersecurity concerns (Raza et al. 2023; Banomyong, 2005). This disparity highlights the ongoing challenge of ensuring equitable access to technological advancements and the need for more inclusive digital transformation strategies in global supply chains.

5.2. Collaboration as Key Resilience Strategies

The findings from this study indicate that flexibility and collaboration are vital for building resilience in maritime supply chains as highlighted in supply chain resilience literature (Christopher and Peck, 2004). The ability to quickly reroute vessels, adjust shipping capacities, and leverage alternative ports has been crucial in mitigating the effects of disruptions like geopolitical tensions and the pandemic (Kamalahmadi and

Parast, 2017; Ivanov et al. 2017). In addition, the literature emphasizes the importance of collaborative relationships between stakeholders in minimizing the impact of disruptions. Osobajo et al. (2021) underline the role of relationship quality, including trust and commitment, in enabling effective coordination during crises.

The COVID-19 pandemic demonstrated the value of strong collaboration and integration among ports, shipping lines, and inland logistics providers. Ports that had established real-time data-sharing and strong partnerships with other supply chain actors were able to better manage congestion and maintain the flow of goods, even during the height of the pandemic (Yuen and Thai, 2017). However, despite the clear benefits, the literature also identifies several barriers to achieving supply chain integration, including misaligned goals, resistance to change, and a lack of trust between stakeholders (Bichou and Gray, 2004). These challenges suggest that while collaboration is a powerful tool for managing disruptions, it requires concerted efforts to overcome institutional and operational barriers.

5.3. Sustainability and Regulatory Pressures in the Maritime Industry

Another major theme identified in both the literature and the study's findings is the increasing pressure on the maritime industry to adopt sustainable practices. The introduction of the International Maritime Organization 2020 sulphur cap and other decarbonization initiatives have forced the industry to invest in green technologies such as LNG-powered ships, hydrogen propulsion, and energy-efficient vessels (Jasmi and Fernando, 2018; Poulsen et al. 2016). These investments are not only necessary for regulatory compliance but also for enhancing the long-term resilience of maritime supply chains in the face of environmental and economic challenges.

The literature on green maritime supply chains aligns with these findings, emphasizing that environmental upgrading in the maritime industry is driven by both external pressures from regulatory frameworks and internal motivations related to market competitiveness and corporate social responsibility (Poulsen et al. 2016). Jasmi and Fernando (2018) argue that green maritime supply chain management is no longer optional but a strategic necessity for shipping lines and ports aiming to remain competitive in a rapidly changing global landscape.

However, as highlighted by both the literature and the findings from this study, the transition to sustainable maritime practices remains uneven. Ports and shipping companies in developed regions have generally made greater progress in adopting sustainable technologies, while those in developing regions face significant barriers related to infrastructure, financing, and technology access (Banomyong, 2005). This suggests that more support, both financial and technical, is needed to enable all actors within the maritime supply chain to transition to green logistics and comply with global environmental standards.

5.4. Risk Management and Resilience

The maritime industry has long grappled with the challenge of risk management, particularly in the face of disruptions such as natural disasters, political conflicts, and pandemics. The literature reviewed highlights the importance of adopting both proactive and reactive strategies to manage these risks (Shen and Li, 2017; Barnes and Oloruntoba, 2005). Proactive strategies, such as building redundancy and maintaining buffer stocks, help to mitigate the impact of supply chain disruptions, while reactive strategies focus on minimizing the damage once a disruption has occurred (Kamalahmadi and Parast, 2017).

The findings from 2019 to 2023 reinforce this need for flexibility-based strategies. Ports and shipping companies that were able to rapidly adjust their operations—by rerouting vessels, switching to alternative suppliers, or leveraging different transportation modes—were better able to navigate disruptions such as the Suez Canal blockage and the Ukraine war (Rogerson et al. 2024). These lessons underscore the importance of building agile and adaptable supply chains that can respond to both expected and unexpected disruptions in a timely and efficient manner.

Looking forward, the maritime industry must continue to prioritize resilience in its operations. As the literature suggests, resilience is not just about managing current risks but also about preparing for future challenges, such as climate change, technological disruptions, and shifts in global trade patterns (Banomyong, 2005). This will require ongoing investment in digital tools, collaborative frameworks, and sustainability initiatives to ensure that maritime supply chains are equipped to handle whatever disruptions may arise.

6. CONCLUSION

The maritime industry is undergoing significant transformation as it adapts to the growing complexity of global supply chains. Ports are no longer just transshipment points; they have become critical players in the logistics network, contributing to supply chain efficiency through their integration with inland transport systems and provision of value-added services. Effective supply chain integration and collaboration are essential for maintaining the smooth flow of goods, but achieving this requires overcoming challenges related to trust, security, and digital transformation. As the industry continues to face new risks and disruptions, building resilience through both proactive and reactive strategies is crucial for ensuring the long-term sustainability of global maritime supply chains.

6.1. Theoretical Implications

This study explores how the maritime industry has responded to major disruptions between 2019 and 2023. It examines the roles of technological innovation, collaborative strategies, and sustainability initiatives in strengthening resilience and ensuring the industry's long-term viability in an increasingly complex global trade environment (Liu et al. 2023a; 2023b; 2023c; Sabahi and Parast, 2020).

Technological innovation has been a central enabler of resilience, with digital tools enhancing supply chain visibility and real-time decision-making (Ambrogio et al. 2022; Modgil et al. 2022; Spieske and Birkel, 2021; Yu et al. 2022). However, uneven adoption across regions highlights the need for more inclusive digital transformation strategies (Kouhizadeh et al. 2021). Flexibility and collaboration have emerged as vital components of resilience, enabling stakeholders to quickly adapt to disruptions (Christopher and Peck, 2004; Friday et al. 2018; Kache and Seuring, 2014). Despite progress, barriers such as misaligned goals and resistance to change continue to impede supply chain integration.

Sustainability has become a critical focus, driven by regulatory frameworks and market pressures (Ampah et al. 2021; Ashrafi et al. 2020). While progress has been made, particularly in developed regions, challenges remain in ensuring equitable access to sustainable technologies. Risk management remains a key priority, requiring a balance of proactive and reactive strategies to navigate future disruptions (Christopher and Peck, 2004; Jüttner et al. 2003; Kamalahmadi and Parast, 2017). Based on

the analysis, discussion and concluding remarks, the study is proposing testable propositions for further studies;

P1: Stakeholders who actively work towards ensuring the accessibility of technological advancements for all actors, will experience higher levels of integration and disruption management capabilities within the maritime supply chain.

P2: Strengthening partnerships and building trust between stakeholders will lead to improved risk management capabilities, resulting in greater disruption management and operational stability during disruptions within the maritime industry.

P3: Maritime supply chains that are encouraged to adopt sustainable practices will show higher adaptability capabilities to their dynamic environments.

P4: Maritime supply chain actors that invest in proactive (e.g., risk assessment, planning) strategies than reactive (re-routing) will demonstrate greater success in developing capabilities to manage future disruptions and to maintain sustainability goals.

6.2. Managerial Implications

By continuing to invest in these areas, the maritime industry can build supply chains that are not only efficient but also resilient enough to manage future disruptions, ensuring the continued flow of goods across the world. Beyond theoretical implications, insights from this study can guide managers in the maritime industry to prepare for and develop capabilities to handle future disruptions. While technological adoptions such as blockchain and real-time data analytics require substantial investment, they prove invaluable when dealing with unexpected events. Therefore, managers may not fully but still significantly benefit from technological adoption in disruption management.

Collaboration remains a pillar of risk management practices (Christopher and Peck, 2004) and continues to be a critical antecedent in mitigating disruption risks (Jüttner et al. 2003). From a holistic perspective, sustainability initiatives can address climate change challenges and reduce the likelihood of environmental and climate-related disruptions. As a final practical implication, flexible risk management strategies designed to cope with the dynamism of the maritime industry can be particularly effective in mitigating disruptions.

6.3. Limitations And Future Research Suggestions

This study also has limitations as it focuses on a specific period and relies primarily on secondary data, despite the richness of the dataset. While the use of UNCTAD reports provides comprehensive and authoritative data, it is acknowledged that relying solely on secondary sources may limit the study's scope. Specifically, the analysis may not fully capture the firsthand experiences or perspectives of stakeholders within the industry. To address these limitations, future research could incorporate surveys and/or semi-structured interviews with stakeholders, as well as include additional documents to extend the time span of the analysis. This approach could yield deeper insights and serve as a valuable starting point for identifying innovative strategies to develop capabilities that mitigate future disruptions.

AUTHOR CONTRIBUTION

All stages of this research were conducted by the author.

Conflict of Interest

The author declares no conflict of interest related to this research.

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