The International Maritime Transport and Logistics (MARLOG 14) - ISSN 2974-3141
http://dx.doi.org/10.21622/MARLOG.2025.14.1.71
Artificial Intelligence Implementations Towards Shaping the Future of Digital World

Blockchain Adoption for Mitigating Maritime Supply Chain Disruptions: Challenges and Opportunities

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ABSTRACT

The global maritime supply chain is prone to disruptions as well as innovations, affecting international trade. Businesses, structures, and organizations continually seek approaches to enhance productivity, reliability, and sustainability. Conversely, Supply chain disruptions are seen as a vulnerability that affects interconnected systems. Geopolitical threats, bottlenecks, labor conflicts, and shortages are major factors in disruptions, leading to increased costs and reduced reliability. While ports have been stable performance indicators, new challenges are pressuring their roles in the supply chain. In this research, blockchain technology (BT) is put forward as a means to mitigate and reduce maritime supply chain disruptions. BT can provide trust, transparency, and alliance in the maritime industry. However, limited research has been conducted on its feasibility and potential limitations. Therefore, the paper offers a conceptual investigation of the impact of BT on managing disruptions and addresses the key determinants and obstacles of its application.

Keywords: Maritime supply chain, Blockchain, Ports, Maritime Disruptions

1. INTRODUCTION

In today's technology-driven world, businesses, structures, and organizations persistently search for methods that enhance productivity, reliability, and sustainability. Disruptions and their consequent impacts are frequently cited as the vulnerability of supply chain structures (Kraus *et al*., 2022). It is of extreme significance that researchers, business partners, and policymakers consider preparing the front lines, making targeted investments in necessary tools, and initiating partnerships to strengthen the resilience and domination of such interconnected systems.

This paper examines the potential influence of blockchain integration on supply chain disruptions in the maritime sector, alongside identifying the key determinants as well as obstacles to blockchain integration in ports and the maritime logistics industry This paper focuses on the applicability of blockchain technology—widely associated with distributed ledgers, smart contracts, and machine-to-machine protocol—in the maritime supply chain operations.

1.1. Background and significance

The shipping and logistics industry is constantly evolving. The past years from COVID-19, inflation, the Ukrainian-Russian war, the Middle East conflict, global climate changes, and other escalating geopolitical tensions—have shown that the global supply chain is prone to disruption as well as innovation. The maritime supply chain is becoming more significant due to international trade, however, it is also operating in an unstable dynamic environment, which twisted global supply chains upside down and exaggerated disenchantment with the trend toward globalization that has controlled world trade for decades (Belhadi *et al*., 2024; Notebooms *et al*., 2021).

Blockchain technology has been hyped as the ultimate technological frontier for linking collaborative networks with rigorous accuracy and consistency requirements. It was initially designed as the underlying architecture for cryptocurrencies. Because of its unique features, researchers have focused on exploring its capabilities in addressing various supply chain issues, ranging from supply chain transparency to supply chain resilience. Many organizations and industry stakeholders have started experimenting with blockchain technology in their supply chain operations to harness these potential benefits. However, despite the growing number of blockchain applications, its adoption level is still relatively low (Zhao *et al*., 2023).

There are limited empirical studies investigating the facilitative role of blockchain in mitigating disruptions in the maritime supply chain. Consequently, it is unclear how and to what extent blockchain can help manage disruptions and help decision-makers with a more rapid and informed decision-making process. In the absence of empirical evidence, the presumed proactive capabilities of blockchain remain largely speculative. Therefore, the paper sets out to investigate the facilitative impact of blockchain on managing disruptions in the maritime supply chain from a port perspective and thus its impact on Port performance.

1.2. Research objectives

In this paper, we investigate the impact of blockchain adoption on mitigating Maritime Supply Chain disruptions from a port perspective with a keen focus on key inquiries that drive our exploration by answering the following research questions :

1. How does the integration of blockchain technology in port operations possibly revolutionize the way ports function?
2. What are the challenges facing ports in implementing blockchain technology?
3. How can blockchain mitigate disruptions?

In general, this preliminary research takes a step toward these directions to identify what makes blockchain technology particularly well suited and what challenges to its successful adoption in managing supply chain disruptions

2. MARITIME & SUPPLYCHAIN DISRUPTIONS

The maritime industry is essential, as 80% of global trade by quantity is carried by sea (UNCTAD, 2019), greatly aiding worldwide economic development as Ports are technically considered as the pillars of the global economy. The maritime supply chain is a complex, integrated system consisting of nodes like seaports, inland ports, intermodal terminals, and connections like sea transport between major seaports and hinterlands. Many parties participate in the maritime supply chain, such as shippers, shipping companies, port authorities and operators, inland transport providers, marine and cargo insurers, and banks, all of whom have interdependent working relationships reflected in various procedures (Nguyen *et al*, 2022).

Disruptions in the global maritime supply chain are characterized as disturbances in the global maritime flow network. Supply Chain disruptions are a major administrative issue due to their inconvenient impacts on businesses and supply chain systems. Organizations must create flexible procedures, which is the ability to survive, adjust, and develop amid all sorts of disturbances (Munir *et al*., 2024).

Maritime stakeholders often face shortcomings in data sharing, system compatibility, and immediate visibility and tracking in supply chain operations due to poor integration of maritime ecosystems. The practices in the maritime industry depend significantly on separate and isolated information management systems confined within each stakeholder (Saberi *et al*., 2019).

A notable instance is when the Port of Kobe needed two years to bounce back from the earthquake in 1995 (Chang, 2019a). Other significant disasters with severe consequences include Hurricane Katrina (2006), the Fukushima earthquake (2011), and the blockage of the Suez Canal by the

container ship Ever Given (2021). Nonetheless, the repercussions of these incidents were comparatively less severe than those of the COVID-19 pandemic, which caused a worldwide shortage of workers, altered buying

habits, restricted shipping capacity, and affected different maritime paths, ports, and the surrounding areas in various ways (Rogerson *et al*., 2024).

Wendler-Bosco and Nicholson (2020) reviewed the literature on the impact of port disruptions in the maritime supply chain and the economic impacts they endure in light of a port disruption that has an adverse influence on the regular operation of the port-hinterland network, port facilities, and the supporting logistical infrastructure. Nguyen *et al*. (2022) used big data, artificial intelligence, and blockchain technology to evaluate maritime supply chain disruptions which are very scarce with maritime port enterprises as the analysis unit. Liu *et al*., (2023) created an exclusive truth through a blockchain application described as the authentication level at the record level in the blockchain. Every update, insertion, or deletion made at the record level remembers the previous record and reflects the updated fields.

2.1. Causes of disruptions

Supply chains must withstand disruptions to function properly. Ensuring the resilience and performance of supply chains requires effective management of disruptions Many studies (Etemadi *et al*. 2021; Nguyen *et al*, 2022; Munir *et al*., 2024 have been done on the risks of supply chain disruptions and strategies to address them. These topics have become even more prominent and have gained significant interest from researchers since the COVID-19 pandemic. Notably, these studies investigated various disruption types, such as demand shock, supply shock, and information disruption, as well as their root causes, frequency, and effects on supply chains (Zhang & K, 2021) and recommended various mitigation strategies, such as supply chain flexibility, collaboration among partners, and real-time monitoring and control systems to respond quickly to disruptions.

2.1.1. Geopolitical disruptions

In recent years, the world has perceived an expansion in geopolitical threats, and conflicts, which has a significant impact on maritime supply chains which is influenced by creating logistical, economic, and security issues by examining the complicated link between geopolitical threats and disruptions in maritime supply networks, Those disruptions have far-reaching drawbacks for industries and overall business subdivisions. The recent influence has developed quickly after the COVID-19 pandemic, the war in Ukraine, the South China Sea, and the situation in the Middle East (Dwar & Bai , 2024). These interruptions may manifest as port closures, disturbances such as shipping routes, elevated insurance costs, and more intense security measures. As a result, these disturbances are important as they can lead to expanded expenses, reduced reliability, obstacles in the supply chain, and hostile effects on global commerce channels.

Dawar & Bai (2024) combined data analysis, current events, and case studies to demonstrate how geopolitical risks—such as political unrest, hostilities, terrorism, and trade disputes—can interfere with marine supply networks. These interruptions may manifest as port closures, disturbances of shipping routes, elevated insurance costs, and more intense security measures. These disturbances are important as they can lead to expanded expenses, reduced reliability, obstacles in the supply chain, and hostile effects on global commerce channels.

Bednarski *et al* (2023) systematically reviewed the impact of geopolitical disruptions on supply chains between 1995 and 2022 to indicate that the impact of geopolitical disruptions on supply chains can be alleviated through: (1) supply chain re-design counting regionalization, back-shoring, and withdrawing just-in-time delivery models as well as (2) the implementation of developing technologies, such as blockchain, 3D printing and artificial intelligence, to improve supply chain transparency and the development of segmented manufacturing.

South China Sea and the Red Sea (Suez Canal) are crucial maritime routes vulnerable to these geopolitical risks, which can result in significant disruptions to global trade. Conflicts in these regions can cause can cause delays, increased costs, and uncertainty for businesses and economies that rely on these routes. The research highlights the far-reaching effects of geopolitical risks, including political volatility, conflicts, terrorism, and trade disputes, on maritime supply chains, resulting in increased costs, decreased reliability, supply chain blockages, and detrimental impacts on worldwide trade movements. The impact of geopolitical risks on maritime supply chain disruptions is an ongoing and dynamic issue (Notteboom *et al*., 2022).

2.1.2. Economic disruptions

One of the earlier reviews by Shen and Li (2016) categorized the supply chain disruption literature into three major areas, namely: demand disruption, supply disruption, and disruption risk. Globalization across manufacturing and assembly stages has significantly reconfigured trade chains. Disruptions propagate quickly, particularly under lean, just-in-time practices characterized by limited inventory holdings and single-source supplies. Additive to trade chain disruptions are other pressures such as pandemics and climate change, and most recently, trade tensions involving major global economic blocks. All these pressures have been especially felt in seaborne global trade, which is perhaps the most difficult mode of transport to reconfigure rapidly (Wang *et al*., 2021)

Supply shocks are sudden and unexpected changes in the supply of critical raw materials, parts, and even production capabilities. This trend not only can cause price increases but also full unavailability of mission- and business-critical parts because of shortages in raw materials, components, or labor needed for their purchase and production. The timing of the effect of a supply shock on a supply chain depends on the state ahead of the supply shock (Notteboom *et al*., 2022).

On the other hand demand shock, is sudden changes in demand for some goods due to unexpected events. For certain products (food, in particular) consumers expect that there might be temporary shortages and then engage in hoarding behaviour, which in turn causes a temporary excess demand and scarcity for many things. In contrast, the demand for non-essentials (such as cars, textiles, furniture, and appliances) tends to be deferred and the need for energy also declines with the reduction in passenger and freight transport (Notteboom *et al*., 2022).

Dubey *et al*. (2021) have identified organizational flexibility as *"the ability of organizations to deploy resources quickly, efficiently and effectively in response to sudden changes in the market conditions", which creates flexibility's clear bond with resilience. Flexibility and dealing with uncertainty.is the pillar for resilience that allows organizations and supply chains to adapt to both predicted and unpredicted changes in the environment (Gaudenzi et al., 2023).*

2.1.3. Environmental disruptions

The connections or routes in the maritime transportation network are called " Maritime Edges." These edges are essential for the effective movement of goods globally. Pratson (2023) stated the 11 major chokepoints that have a critical role in energy transportation, the global economy, and sustainable development. (1) Panama Canal, (2) Gibraltar Strait, (3) English Channel, (4) Danish Straits, (5) Bosporus Strait, (6) Suez Canal, (7) Bab El Mandeb Strait, (8) Strait of Hormuz, (9) Malacca Strait,

(10) Lombok-Makassar Strait, and (11) Ombai Strait, addressing the Strategic narrow waterways like the Panama Canal, Suez Canal, and Strait of Hormuz are crucial bottlenecks in the global maritime trade network. Each maritime chokepoint holds unique strategic importance based on its location, historical context, infrastructure, and the existence of other sea routes

Disruptions in these critical passages can have significant worldwide impacts. In case of closure (The six-day blockage of the Suez Canal by the mega-container ship Ever Given in March 2021 (Faucon, 2021), substantially the blockage caused significant delays and disruptions in global supply chains.

Supply chain disruptions arise from various factors, including organizational, supply chain-related, and environmental risks. While it is relatively easier to estimate natural hazards, the intermediate and long-term responses of firms and regions are more challenging to predict. Natural disasters have led to widespread disruptions in supply chains, with decreases in firm presence, maritime operations, and changes in port infrastructure. The increasing frequency and impact of these natural disasters have highlighted the need for supply chain resilience and the assessment of their cumulative effects on operational continuity (Rahman et al., 2022).

In particular, with the advancement in the field of nature and environment sciences, it is relatively easier to estimate earthquakes, volcanic activities, hurricanes, and droughts, but it is not that probable to estimate and even shape the firm and regional responses intermediate and long-term results. Natural hazard damages have led to nationwide firm presence at its lowest rates and on a universal scale, maritime gate and large terminal operations cuts taking place year after year and even on a very large scale extensive erosion and change in port shape have been experienced (Notteboom et al., 2021).

Disruptions arising at the supply chain level due to natural disasters increase gradually, along with fiscal losses calculated in the total caused by these disasters, which are forecasted to surge, and consequently, the necessity to spot the cumulative impact level of the supply chain of natural disasters with management and operational continuity responsibility through the role of resilience in supply chains arise (Monios & Wilmsmeier, 2022).

2.2. Impact on Port operations

In 2024, several significant maritime disruptions have impacted global shipping routes. Increased attacks on vessels in the Red Sea forced many ships to take longer routes, affecting global trade. The Panama Canal also faced severe constraints, causing many shipping lines to shift their routes to the Suez Canal, increasing transit times and costs for importers. Rerouting vessels away from the Red Sea and Panama Canal had increased global vessel demand by 3% and container ship demand by 12%, compared to what it would have been without these disruptions. This added significant pressure to global logistics and strained supply chains (UNCTAD, 2024).

Maritime supply chains involve many stakeholders, and the ports, connecting the land and water parts of the supplies, are essential parts of such supply chains. It makes sense to look into maritime supply chains from the port level. Ports are instrumental in ensuring the resilience of maritime supply chains. The role of a port in the route depends on the relative match between the supplier and the demand location for the products moved across the port. Based on time and space characteristics; there are three types of port roles as a gateway, hub, or a combination of both—witnessed discontinuity in the flows. Ten months into the pandemic (April 2021), the shipping flows have seen fluctuations and changes in the routes and vessels rescheduled in different shipping services (Notteboom & Rodrigue, 2023).

Major ports like those in Singapore experienced increased congestion due to vessel rerouting, leading to off-schedule arrivals and longer waiting times. Heightened geopolitical tensions in the Middle East further disrupted maritime routes, adding complexity to global shipping logistics. These disruptions have had a ripple effect, causing delays and increased costs in the supply chain, influenced by factors such as distance, fuel costs, and political stability (Notteboom et al , 2024).

Port disruptions have far-reaching impacts and their potential can be exposed by disruptions like the recent global ones (Klar et al., 2023). Ports have an absolute part to play in mitigating disruptions thus improved resiliency can offer pivotal benefits in terms of supply chain performance. In addition to offering resiliency, ports are also seen as a facilitation point for port community-systems and single window artefacts enabling both public authorities and the private sector to obtain information confidentially and securely.

3. BLOCKCHAIN TECHNOLOGY IN SUPPLY CHAIN MANAGEMENT

Supply Chain Management (SCM) is a vast field and is the backbone of all industries (Hughes et al., 2019). Nonetheless, conventional supply chain systems lack the flexibility and clarity required to meet the increasing needs of the future, resulting in significant expenses related to error correction, costs, administration, and fraud prevention (Dutta et al., 2020).

Blockchain has the potential to transform SCM through its features of transparency, authenticity, trust, security, cost reduction, disintermediation, efficient operations, and reduced waste (Philipp et al., 2019; Gurtu and Johny, 2019). Its distributed nature helps mitigate risks associated with piracy, hacking, vulnerability, compliance costs, and contractual disputes (Sheel and Nath, 2019).

Blockchain enables real-time order settlement, automation of manufacturing tasks, and mitigation of the ripple effect in supply chains by minimizing disruptions caused by changing paradigms. Overall, blockchain offers various benefits for improving the efficiency and resilience of supply chain operations (Chang et al., 2019a; Wang et al., 2019a; Saberi et al., 2019; Surjandy et al., 2019a).

Liu et al., (2019) stated that blockchain supports supply chain resilience by minimizing the effects of disruptions, using a preventive and proactive strategy for managing risks, and offering multiple layers of protection for the supply chain network The way blockchain is structured allows it to address both organizational and network risks linked to any supply chain.

While Etemadi et al. (2021) Manzoor et al. (2022) and Rauniyar et al. (2023) Vijayakumar et al. (2024) have observed that blockchain is a burgeoning technology widely acknowledged for its capacity to enhance traceability and auditability across diverse industries, they discussed the significant potential of blockchain to elevate the supply chain landscape by incorporating improved security, privacy, and data transparency and proved that blockchain can assist in managing and reducing the impact of disruptions in the supply chain.

3.1. Overview of blockchain technology

A Blockchain is a decentralized peer-to-peer network consisting of a chronological chain of blocks that sustains records and validates data, making it challenging or impractical for another institution to change, erase, or add on without the agreement of a shared acknowledgment method (Liu et al., 2023) which makes it very safe to business operations. It has endless applications in various fields like designing smart contracts (programs automatically executed according to contract terms) (Li et al. 2023b) to track finance fraud or securely share medical records between healthcare professionals.

Blockchain transactions are recorded in interconnected blocks. Each block contains a unique ID and the previous block's hash, ensuring security and transparency. Transactions are validated, time-stamped, and chronologically arranged, making the system trustworthy and irreversible. The "consensus mechanism" is an important element that enables the network to work together in determining when to add new blocks, ensuring the reliability of past data through joint effort (Liu et al., 2023). To implement blockchain with these functions, Fig. 1 shows the typical "workflow" of using blockchain for a transaction. Note down that this workflow is standard (see Fu and Zhu, 2019a).

Blockchain has great potential to change every stage of the supply chain, from getting raw materials to delivering products to customers (Babich and Hilary, 2019). It also allows for restructuring the supply chain by creating a business process reengineering framework based on blockchain (Chang et al., 2019a). Each transaction can be organized through blockchain technology, making the process quicker and more secure (Queiroz et al., 2019).

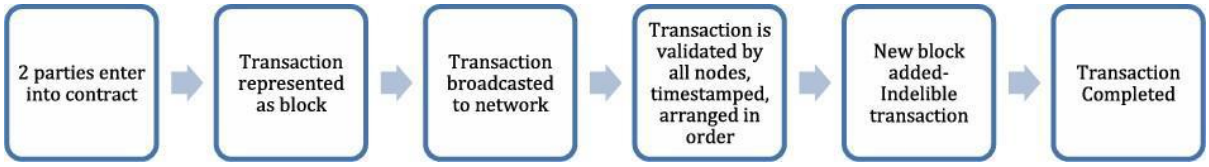

Figure 1: Blockchain Workflow (Dutta et al., 2020)

3.2. Benefits and applications in the ports industry

The distributed operation of the information maintenance solution implies an equivalent distribution of the operational and capital expenditure costs. The popularity of blockchain technology has led to articles proposing its adoption in almost all sectors, including private, public, energy, financial, record keeping, and identity management. However, blockchain is not a panacea and has to be carefully applied to provide solutions where its benefits justify its cost, mainly due to the computational intensity (Kapnissis *et al*,2020).

Meanwhile, Kwesi-Buor *et al*., (2019) examined the effects of policy actions on how industry participants are ready to handle risks and bounce back from interruptions within the maritime logistics and supply chain system. They also modeled how forecasting precision, technological advances, risk prevention attitudes, port operations, and the port environment influence disaster readiness. The researchers discovered that there is a two-way relationship between regulations and the behaviour of industry participants.

In addition, Nguyen *et al* (2023) presented that 83% of the studies reviewed (i.e. 39 out of the total of 47 papers) used mathematical models as tools to mitigate disruptions in the maritime industry, it is confirmed that mathematical optimization has been considered in current technology adoption in supply chain management strategies in general, and maritime industry in particular. Mathematical models are applied in addition to technologies on indicated planning applications, not only for greater efficiency and profitability but also for managing and mitigating disruptions and promoting resilience.
In recent years, stakeholders have minimized time-consuming and expensive paperwork by exchanging information through electronic data interchange (EDI). Nevertheless, third-party managed EDIs offer less visibility, leading to stakeholder trust concerns (Tiwari *et al*., 2023). Conversely, blockchain holds great potential as a reliable platform to enhance trust among parties involved, its success relies on thorough collaboration within the industry, as highlighted by the recent failure of TradeLens. Some experts suggest that the hesitance to share data among shipping companies may have contributed to the downfall of TradeLens (Maersk, 2022).

Blockchain can also improve trust among maritime stakeholders by decreasing instances of counterfeiting, fraud, theft, and human mistakes. Its unique ability to securely track and share information among various stakeholders helps prevent counterfeiting in ways other technologies cannot (Bhatia *et al*., 2019). The maritime supply chain has started to adopt blockchain to combat the widespread issue of counterfeit goods through the use of smart tags and seals (Maritime Fairtrade, 2023). Trust issues arising from fraud and human error persist among maritime stakeholders. For instance, fraudulent activities related to bills of lading may include falsified signatures, incorrect cargo descriptions, and underreporting to evade taxes. Reports indicate that as much as 10% of bills of lading contain errors that could result in disputes and legal action (DHL, 2019).

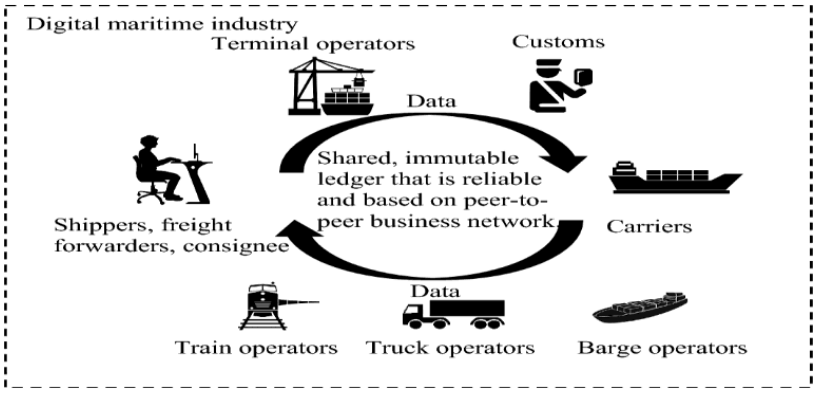

Figure 2: Blockchain in the maritime industry Li et al., (2024)

Figure 2 shows a maritime supply chain supported by blockchain technology. It features key Stakeholders in the industry and highlights that all transaction data is shared and cannot be changed, ensuring a clear, trustworthy, and safe system. Information related to important stakeholders is provided below. For a detailed list of stakeholders, refer to Duru *et al*., (2020).

- Shippers: share information about shipping guidelines.
- Freight Forwarders: share information on transport plans, local occurrences, transfers between transport modes, and document processing
- Terminal Operators: share updates on how containers are transferred among ships, trucks, and freight trains
- Carriers: provide details on the shipment's location during the ocean transport phase.
- Customs authorities: share the customs clearance status for cargo imported and exported to and from a country.
- Port Authorities: offer insights into regulations, ship traffic, safety and security measures, and economic growth related to port operations.
- Beneficial Cargo Owners in the blockchain network can access details from an ocean carrier's or freight forwarder's online booking system and receive automated updates on shipments and port activities.

Dutta *et al*., (2020) mentioned that blockchain applications have a positive impact on different industries and the shipping industry is one of them as well as proved that it creates a verifiable and distributed shipping system to integrate and interrelate all the business activities, improve the maritime industry by organizing projects, people, information, payment and communication in safer and efficient customs, certifies minimum delays in real-time transactions, transparency of transactions from remote areas, extra vigilance for data privacy, transaction validation and fraud management also, Blockchain-based solution with IoT enabled smart containers, smart contracts can be used to manage shipments, automate payments, track defilements and make the whole SC efficient.

4. CHALLENGES IN BLOCKCHAIN ADOPTION IN PORTS

The progressively automated maritime sector's equilibrium between efficiency and security is essential. Blockchain technology, with its capacity to transform seaport data management, is particularly remarkable (Liu *et al*., 2021). However, blockchain integration within seaports has been gradually hindered by a range of internal and external obstacles.

Internally, seaports face resistance to the adoption of new technologies, stemming from previous IT failures and a lack of technical expertise among administrators, which obscures the perceived advantages of blockchain (Kaur *et al*., 2022).

Externally, seaports encounter challenges such as outdated regulations and strict data privacy laws, which create apprehension towards adopting innovative technologies like blockchain. Additionally, the slow evolution of industry standards complicates the justification for investments in these rapidly advancing technologies (Öztürk & Yildizbaşi, 2020).

The specific barriers that impede progress are detailed in Table 1 based on (Guan *et al*., 2023;2024). To overcome these challenges (refer to Table 1), organizations must address issues of distrust, resistance to change, and uncertainty regarding new technologies (Kaur *et al*., 2022).

Table 1: Blockchain barriers in the Port industry (Guan et al., 2023)

List of Internal Barriers	List of External Barries
1. Lack of Management Commitment support	1 Lack of customer awareness
2 Lack of internal information transparency	2. Lack of external stakeholders' involvement
3 Lack of new organizational Policies	3. Collaboration and Coordination Challenges
4 Lack of Knowledge and expertise	4. Market Competition and uncertainty
5 Difficulty in Changing Organizational Culture	5. Lack of governmental Policies/ standardization
6 High Cost	6. Lack of early adopters

A constructive attitude and commitment are crucial for the successful implementation of technology. Furthermore, accommodating the unique characteristics and cultures of companies is vital for effective execution.

The challenges associated with the application of blockchain in port operations stem from external influences, including governmental, industrial, institutional, and community-related concerns (Kouhizadeh *et al*., 2021). These challenges encompass the necessity for supportive government policies, unpredictable market competition, and insufficient stakeholder engagement in the realms of sustainability and blockchain adoption (Guan *et al*., 2024) while (Dutta *et al*., 2020) proved that due to lack of complete and integrated information, blockchain adoption remains a challenge in the shipping industry. Information flow needs to be developed and a distinctive blockchain model needs to be designed which will help integrate all the confused stakeholders.

5. BLOCKCHAIN ENHANCES PORT SUSTAINABILITY PERFORMANCE

Ports can enhance sustainability and navigate the complexities of blockchain integration by adopting effective practices. The Triple Bottom Line framework evaluates the influence of blockchain on port sustainability through economic, social, and environmental lenses (Jum'a *et al*., 2022). From an economic perspective, blockchain presents opportunities for cost reductions and the generation of new revenue sources for ports (Wang *et al*., 2021). The automation of processes leads to increased efficiency, lowering overhead costs and diminishing the likelihood of disputes, fraud, and delays through enhanced transparency and automated settlement processes (Gao *et al*., 2022).

On a social level, blockchain contributes to the welfare of individuals involved in port activities by promoting fair labor practices and safety. It enhances consumer confidence by ensuring the traceability of product origins and preventing the distribution of illegal or harmful goods, thereby protecting local communities (Shiau & Chuang, 2013).

Environmentally, blockchain plays a crucial role in reducing the ecological footprint of port operations. By facilitating transparent monitoring of carbon emissions and waste, ports can adhere to environmental standards and encourage more sustainable practices (Yadav *et al*., 2020).

Blockchain effectively addresses sustainability challenges within ports. The re-engineering of business processes through blockchain technology provides a transparent ledger that accurately records sustainability metrics, including emissions, waste, and supply chain practices (Battilani *et al*., 2022). Using blockchain can solve sustainability issues in ports. It helps reshape business processes with a clear record of sustainability metrics, like emissions and waste. This gives ports valuable data on their environmental impacts, energy use, and how they manage waste and supply chains. (Saberi *et al*., 2018).

Furthermore, blockchain equips management with real-time data, facilitating informed decision-making regarding sustainability, resource distribution, and progress assessment (Galati, 2021). This alignment of port strategies with sustainability objectives is crucial for long-term success.

6. CONCEPTUAL FRAMEWORK

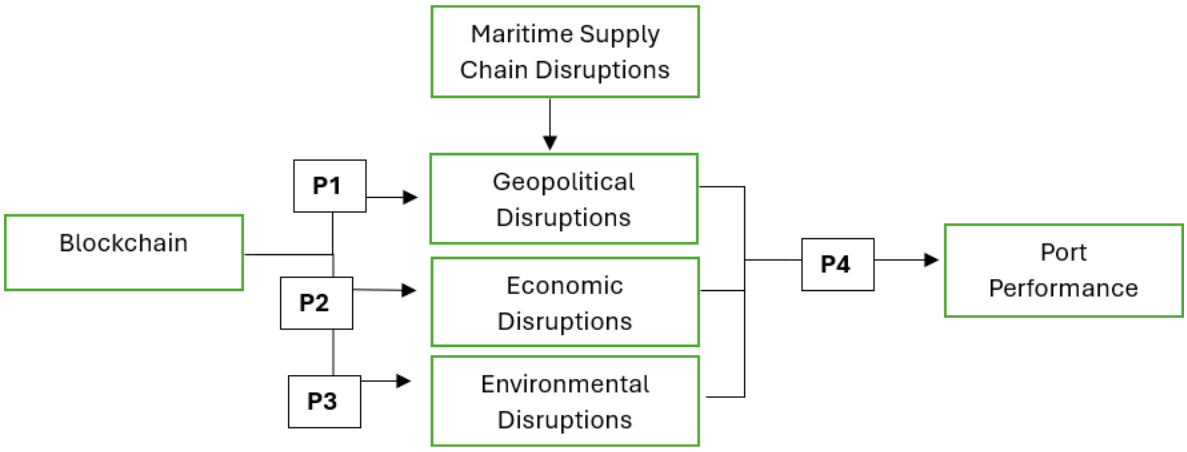

Figure 3: Blockchain adoption in managing Maritime Supply chain Disruptions (Developed by Author)

The proposed framework for blockchain adoption in mitigating maritime supply chain disruptions emphasizes the integration of blockchain technology to enhance transparency, trust, and efficiency across the supply chain. This framework involves the application of distributed ledgers to ensure real-time visibility and traceability of goods, smart contracts to automate and secure transactions, and decentralized data sharing to improve collaboration among stakeholders. By addressing key challenges such as lack of trust and inefficiencies in current systems, the framework aims to mitigate disruptions caused by geopolitical, economic, and environmental factors. The adoption of blockchain technology is expected to streamline port operations, reduce administrative costs, and enhance the port performance thus enhancing overall resilience and sustainability of the maritime supply chain.

7. CONCLUSION

The Maritime Supply chain has entered the era of big data, while blockchain technology has emerged as a transformative force. It is widely recognized that blockchain possesses significant potential to revolutionize supply chains, both on a global and local scale, by enhancing operational efficiency, data management, responsiveness, transparency, and the management of smart contracts. The advent of blockchain technology presents an opportunity for organizations, including companies and governments, to gain a competitive edge. Various enterprises and nations are investing in the exploration of new blockchain applications to achieve improved operational efficiency. In this paper, we discussed how the emerging blockchain technology features and benefits can be leveraged for port logistics operations and enhance its performance through mitigating and managing maritime supply chain disruptions (geopolitical/economic/environmental). It highlighted various applications

and use cases of blockchain technology In summary, the paper contributes to knowledge advancement in mutually academia and industry by filling research gaps and generating new insights. The research also highlights the social impact of applying blockchain technology in ports and emphasizes the importance of designing policies to enhance overall social performance and achieve multiple-win outcomes.

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