BLOCKCHAIN AND SMART CONTRACTS: REVOLUTIONIZING CONTAINER SHIPPING IN THE CONTEXT OF INDIAN PORTS IN THE GLOBAL SUPPLY CHAIN

Submitted to the School of Maritime Management, Indian Maritime University in partial fulfillment for the award of degree in MBA International Transportation and Logistics Management

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DECLARATION

I, **Harikrishnan M** student of the School of Maritime Management, Indian Maritime University –Chennai Campus, hereby declare that this Project report titled **'BLOCKCHAIN AND SMART CONTRACTS: REVOLUTIONIZING CONTAINER SHIPPING IN THE CONTEXT OF INDIAN PORTS IN THE GLOBAL SUPPLY CHAIN'** submitted in partial fulfillment of the requirement for the degree of Master of Business (MBA) in International Transportation and Logistics Management is my original work carried under the guidance of my project guide. It has not formed the basis for the award of any Degree/Diploma of any University/Institution. The information submitted is true and original to the best of my knowledge.

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CERTIFICATE

This is to certify that the project report entitled **'BLOCKCHAIN AND SMART CONTRACTS: REVOLUTIONIZING CONTAINER SHIPPING IN THE CONTEXT OF INDIAN PORTS IN THE GLOBAL SUPPLY CHAIN'** submitted to the School of Maritime Management, Indian Maritime University, Chennai Campus., in partial fulfillment for the award of the degree of Master of Business Administration (MBA) in International Transportation and Logistics Management, is a record of work carried out entirely by **Harikrishnan M,** Reg. No. **2203305013.**

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ABSTRACT

The container shipping industry plays a pivotal role in facilitating global trade, yet it grapples with inefficiencies, transparency deficits, and security vulnerabilities within its traditional operational framework. The emergence of Blockchain technology has ushered in a revolutionary paradigm shift, offering innovative solutions to address these longstanding challenges. This academic report delves into the transformative impact of Blockchain technology and smart contracts on container shipping operations. Through a comprehensive analysis of current industry challenges, technological advancements, and practical applications, the report elucidates the potential of Blockchain and smart contracts to revolutionize supply chain management in the container shipping sector. It explores the decentralized and immutable nature of Blockchain, its trust-building capabilities, and the automation potential of smart contracts. Drawing on relevant literature and case studies, the report examines how Blockchain and smart contracts facilitate provenance tracking, real-time visibility, and automated payment settlements, thereby enhancing operational efficiency and reducing costs. Furthermore, the report critically evaluates the challenges associated with implementing Blockchain and smart contracts in container shipping, offering insights into strategies for overcoming regulatory, technical, and organizational hurdles. By fostering collaboration and innovation, stakeholders can harness the transformative power of Blockchain technology and smart contracts to drive sustainable growth and competitiveness in the container shipping industry.

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LIST OF ABBREVIATIONS

Abbreviation	Description
TEU	Twenty-foot equivalent unit
IoT	Internet of Things
GDPR	General Data Protection Regulation
PoW	Proof of Work
PoS	Proof of Stake
HFO	Heavy fuel oil
GHG	Greenhouse gases
IMO	International Maritime Organisation
B/L	Bill of Lading
THC	Terminal Handling Contracts
RFID	Radio Frequency Identification
DeFi	Decentralized finance
DApps	Decentralized Applications
BDS	Blockchain digital systems
TAM	Technology Acceptance Model
SC	Supply Chain
ICT	Information and communication technology
AI	Artificial Intelligence

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CHAPTER I
INTRODUCTION

1.1 Container shipping: An overview

Maritime shipping is the backbone of global trade, transporting an estimated 80% of all commodities by sea. The number of goods moved by ships has expanded in tandem with the global economy's expansion during the last few decades. In 2021, over 1.95 billion metric tonnes of cargo were handled worldwide, up from around 0.1 billion metric tonnes in 1980. Naturally, the worldwide container fleet has increased in size. Between 1980 and 2022, container ships deadweight tonnage increased from 11 million to 293 million metric tonnes. The Mediterranean Shipping Company is the world's largest container ship operator, with a total capacity of nearly 5 million TEUs, followed by APM-Maersk CMA CGM, COSCO, and Hapag-Lloyd.

In 2022, Asia-Pacific has the world's leading container-handling ports. The port of Shanghai was the world's busiest container port in 2022, processing approximately 47 million TEUs of containerised freight. In addition to the Asia-Pacific area, North America and Europe serve as key containerised transport hubs. In fiscal year 2022, the Port of Los Angeles handled about 10.7 million TEUs, making it the largest container port in the US. The Port of Rotterdam is Europe's largest container port, processing more than 8.3 million cargo in 2022.

The busiest container ports in Asia are Shanghai, Singapore, and Hong Kong. In the United States, the neighbouring ports of Los Angeles and Long Beach comprise the country's largest container hub. Rotterdam, Hamburg, and Antwerp are home to Europe's largest ports. In terms of value, seaborne cargo carried by container ships is the most important type of waterborne freight, and container handling is one of the primary revenue streams generated by port operation and management. Intermodal containers typically have a capacity of one or two twenty-foot equivalent units, also known as TEUs. PSA International of Singapore is one of the world's leading maritime port operators, followed by Hutchison Port Holdings, headquartered in the British Virgin Islands. PSA

International operates various ports worldwide, generating over 4.7 billion Singapore dollars in revenue in 2021.

1.2 History of Container Shipping

Before the invention of intermodal shipping containers, commodities were shipped in various-sized boxes that had to be manually loaded and unloaded onto and from ships by workers. Transporting things in this manner was inefficient, costly, and time-consuming. Furthermore, it made loading freight onto various modes of transportation extremely difficult. When the first standardized intermodal shipping container was developed in the 1950s, it sparked a revolution in international trade.

In 1956, an entrepreneurial trucker named Malcolm McLean, looking for a cheaper way to transport freight between New Jersey and Texas, put 58 trailer bodies onto the World War II vintage tanker, the TS Ideal X, kicking off what we now call "Containerisation." From this humble beginning, the container business has grown into a sophisticated worldwide transportation system that handles more than 100 million units of containerised freight each year. To support this containerised system, over 37 million teus travel in more than 19 million vessel slots and on roads, trains, and waterways around the world, carrying a wide mix of cargo in a safe, secure, efficient, and ecologically friendly manner.

The container and chassis leasing sector grew to assist containerised trade by providing high-quality equipment and services. Today, the leased fleet has a replacement value of around $53 billion for the 20 million container TEUs and 500,000 to 600,000 chassis.

Containers and chassis are offered in a variety of configurations to satisfy customer requirements. Equipment can be chosen based on length and height; closed, open-top, or flat rack; dry or liquid cargo; refrigerated or ambient; fixed wheelbase or slider, tandem or tri-axle; straight frame or drop frame; or other characteristics to satisfy cargo requirements.

Shipping containers lowered shipping time and cost while also allowing containerised items to be readily transported between different modes of transport. Efforts to improve shipping containers persisted, and in the 1970s, a refrigerated container (reefer) was developed. Container shipping has grown in popularity since the arrival of reefers, which allow for the transfer of perishable items such as food.

Reflecting the increasing volume of commodities transported by container ships, the worldwide shipping container market is predicted to more than double in the coming years.

1.3 Container shipping in India

Container shipping in India has experienced substantial growth and development over the past few decades. Container ships in global trade networks typically follow established routes, which are more predictable compared to routes taken by bulk dry carriers and oil tankers [1](Kaluza et al., 2010). The evolution of maritime supply chains in India commenced in the 1980s and has since expanded, contributing to the country's increased involvement in international trade[2](Kashav et al., 2021). India's cargo volume significantly influences vessel deployment and de-hubbing decisions in maritime networks, prompting shipping lines to consider direct routes to Indian ports rather than utilizing intermediary hubs like the Colombo Port[3] (Kawasaki et al., 2022).

India's tryst with container shipping began in the 1960s, with the establishment of modern container terminals in major ports like Mumbai and Kolkata. The introduction of Container Corporation of India (CONCOR) in 1988 further bolstered India's containerization efforts, laying the foundation for a robust logistics infrastructure. Over the years, Indian ports have witnessed significant investments in container terminal development, enhancing their capacity and efficiency. India's container throughput has witnessed steady growth, driven by factors such as increasing trade volumes, infrastructure development, and policy reforms. Major ports like Jawaharlal Nehru Port Trust (JNPT), Mundra Port, and Chennai Port handle a significant portion of India's container traffic. However, challenges such as port congestion, inadequate hinterland connectivity, and bureaucratic red tape continue to pose challenges to the sector's growth.

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[1] Kaluza, P., Kölzsch, A., Gastner, M., & Blasius, B. (2010). The complex network of global cargo ship movements. Journal of the Royal Society Interface, 7(48), 1093-1103. https://doi.org/10.1098/rsif.2009.0495

[2] Kashav, V., Garg, C., & Behera, S. (2021). Evolution of maritime supply chains of containerised freight in india: taaffe, morrill and gould model revisited. International Journal of Logistics Systems and Management, 38(1), 105. https://doi.org/10.1504/ijlsm.2021.112447

[3] Kawasaki, T., Tagawa, H., & Kavirathna, C. (2022). Vessel deployment and de-hubbing in maritime networks: a case study on colombo port and its feeder market. Journal of Marine Science and Engineering, 10(3), 304. https://doi.org/10.3390/jmse10030304

Challenges in routing and scheduling are prevalent in the liner container shipping industry, underscoring a gap between academic research and industry requirements (Meng et al., 2014). The demand for diesel in India is projected to double from 52.33 million tonnes in 2006 to 104.3 million tonnes by 2020, emphasizing the necessity for efficient shipping operations to meet escalating energy needs[4] (Ajith et al., 2021). Analyzing the future of container shipping in Iranian ports offers insights into traffic forecasts and connectivity indices, which can be valuable for anticipating trends in Indian container port development (Panahi et al., 2017).

Efficient container shipping operations hinge on factors such as sailing speed optimization, which can impact schedule reliability and logistics costs for customers (Notteboom, 2006; Wang & Meng, 2012). Trade flow imbalances and capacity limitations present challenges to fully capitalizing on the benefits of containerization in global supply chains (Notteboom & Rodrigue, 2008). Understanding the spatial distribution and centrality of ports is crucial for optimizing maritime logistics and enhancing port transport business, particularly concerning regional competitiveness with neighboring countries like Myanmar[5] (Saha, 2017; Jeon et al., 2019).

The maritime industry in India plays a pivotal role in the country's economic progress, with a significant portion of India's trade volume and value being conducted through maritime transport. The strategic optimization of empty container logistics in major shipping companies underscores the importance of efficient container management for seamless operations and cost-effectiveness. Furthermore, the potential for lightweight constructions using advanced materials like syntactic foams presents opportunities for innovation in shipbuilding and marine industries in India[6] (Bakshi & Kattimani, 2022). Several trends are shaping the Indian container shipping industry, including the adoption of digital technologies, emergence of mega-container vessels, and the rise of specialized

[4] Ajith, B., Math, M., Patel, G., & Parappagoudar, M. (2021). Engine performance and exhaust emissions of garcinia gummi-gutta based biodiesel–diesel and ethanol blends. Sn Applied Sciences, 3(5). https://doi.org/10.1007/s42452-021-04537-0

[5] Saha, R. (2017). Innovation in maritime logistics industry of bangladesh for doing port transport business. Journal of Shipping and Ocean Engineering, 7(2). https://doi.org/10.17265/2159-5879/2017.02.005

[6] Bakshi, M. and Kattimani, S. (2022). Probing the effect of post-curing and halloysite nanotube reinforcement on thermo-mechanical properties of lightweight epoxy syntactic foam composites. Proceedings of the Institution of Mechanical Engineers Part L Journal of Materials Design and Applications, 237(3), 697-713. https://doi.org/10.1177/14644207221122906

terminals. Digitalization initiatives such as blockchain, IoT, and AI are revolutionizing supply chain management, enhancing visibility, and optimizing operations. Moreover, the deployment of larger vessels is driving consolidation among shipping lines and reshaping port infrastructure requirements.

Container shipping in India is a dynamic and essential element of the country's trade and economic landscape. By leveraging insights from global maritime research and addressing key challenges in routing, scheduling, and port operations, India can further strengthen its position in the international container shipping market and foster sustainable growth in the maritime sector.

1.4 Changing dynamics of Global supply chain

The dynamics of global supply chains have undergone significant transformations in recent years, influenced by various factors such as technological advancements, global changes like the COVID-19 pandemic, shifts in consumer behavior, and evolving market demands. These changes have made supply chains more unpredictable and volatile, necessitating a re-evaluation of strategies to ensure sustainable resilience Grzybowska & Stachowiak (2022). The interplay between globalization and supply chain vulnerability to natural disasters highlights the intricate relationship between global interconnectedness and risk exposure (Kalafsky & Conner, 2014).

The COVID-19 pandemic has had a profound impact on global supply chain operations, prompting the need for a systemic approach to analyze and address the complexities within supply chains (Heidary, 2022). Global sourcing and international logistics have introduced new risks to supply chains, emphasizing the importance of supply chain integration and risk management to enhance performance and mitigate vulnerabilities (Duoming & Chin, 2022). Behavioral tendencies of supply chain managers in the context of globalization underscore the need for adaptive strategies to navigate the evolving landscape of global trade (Nagranová, 2019).

The multi-tier analysis of the medical equipment supply chain network sheds light on the implications of disruptions and the importance of location characteristics in influencing supply chain performance (Lavassani et al., 2022). The aftermath of the COVID-19 pandemic has raised questions about the sustainability of neoliberal globalization and its impact on global supply chains, particularly in light of environmental considerations and climate change concerns (Free & Hecimovic, 2021).

The evolving landscape of supply chain risk management in response to challenges like the COVID-19 pandemic underscores the need for adaptive strategies and digital innovations to enhance supply chain flexibility and resilience ("China Transport Supply Chain Risk Management Challenges Face to Covid-19 Analysis", 2022).

Supply chain complexity is a key consideration in global operations, with various factors such as production locations, trade agreements, and interdependencies contributing to the intricacies of supply chain design decision-making (Asmussen et al., 2017). The reallocation of global supply chains in response to disruptions like the COVID-19 pandemic highlights the need for adaptive strategies and contingency management to ensure supply chain continuity (Ye, 2024). User-driven supply chain business model innovation and collaborative initiatives play a crucial role in reshaping supply chain networks and enhancing sustainability in the face of dynamic market conditions (Sun et al., 2021; Shan et al., 2020).

The impact of the COVID-19 pandemic on global textile and apparel supply chains underscores the vulnerabilities exposed by disruptions and the need for strategic reevaluation of supply chain management practices (Su et al., 2022). Contingency management approaches in supply chain performance highlight the importance of adaptive strategies to address unexpected incidents and maintain operational continuity (Sang-Hoon et al., 2020). Dynamic optimization approaches for supplier selection in flexible supply chains emphasize the need for agile strategies to navigate the dynamic global market environment (Chibani et al., 2014).

The global supply-chain effects of COVID-19 control measures have underscored the interconnected nature of supply chains and the ripple effects of disruptions across industries (Guan et al., 2020). Collaboration and dynamic response systems are essential for overcoming challenges in healthcare supply chains and ensuring resilience in the face of global health crises (Lee et al., 2020). Public policy implications on global supply chain capabilities and performance emphasize the role of resources and strategic planning in enhancing supply chain resilience and adaptability (Morash & Lynch, 2002).

The changing dynamics of global supply chains necessitate a proactive and adaptive approach to supply chain management. By leveraging insights from research on supply chain resilience, risk management, and dynamic capabilities, organizations can navigate the complexities of global trade and enhance their competitiveness in an ever-evolving market landscape.

1.5 Objectives of the study

a. Examine how blockchain can enhance transparency, traceability, and efficiency in logistical processes, and identify areas where it can be most beneficial in container shipping at Indian ports.

b. Assess the feasibility and impact of implementing smart contracts in Indian ports. Examine existing contractual processes and determine how smart contracts can automate them, reduce paperwork, and minimize disputes.

c. Investigate the effects of blockchain and smart contracts on Indian port operations.

d. Identify and propose practical solutions to the major barriers to the adoption of blockchain and smart contracts in Indian ports.

Methodology

As integral components of the global supply chain, blockchain, and smart contracts have the potential to revolutionize container shipping within Indian ports. In the first step of the study, extensive literature reviews were complemented by expert interviews in order to identify current uses and potential areas for blockchain integration in Indian ports. Through this approach, we were able to gain a deeper understanding of how blockchain technology can enhance transparency, traceability, and efficiency in port logistics. The feasibility and impact of smart contracts were then evaluated by reviewing existing contract management systems and conducting case studies on ports that have implemented smart contracts in pilot projects. Analysing these digital contracts aimed to determine how they could streamline processes, reduce administrative overhead, and automate operations. The third objective involved quantifying the efficiency of supply chains using blockchain and smart contracts. In pilot settings, key performance indicators such as turnaround times, cost efficiency, and security incidents were collected before and after these technologies were implemented. The survey and interviews with supply chain stakeholders provided additional insights into operational improvements. The study also identified barriers to adoption by engaging with regulatory authorities, technology providers, and port operators to identify regulatory, technological, and organizational obstacles. As a result of workshops and focus groups, actionable strategies were developed for overcoming these challenges and enabling more seamless adoption of block chain and smart contracts in Indian ports. As a result of this methodological framework, a thorough examination of how these technologies enhance the efficiency and security of container shipping through Indian ports was conducted.

CHAPTER II
LITERATURE REVIEW

2.1 Understanding Blockchain Technology- Simanta Shekhar Sarmah(2018)

This paper by Simanta Shekhar Sarmah offers a foundational overview of blockchain technology, highlighting its key features, applications, and potential benefits across various industries. Sarmah defines blockchain as a transparent money exchange system, emphasizing its role in transforming business operations. The paper positions blockchain as a secure and tamper-proof digital ledger operating on a peer-to-peer network. This aligns with the established understanding of blockchain technology as a distributed ledger that facilitates secure and transparent record-keeping without the need for a central authority. The paper cites the significant investment pouring into the blockchain market, with an estimated net worth exceeding $3 trillion within the next five years. This aligns with industry trends highlighting the growing popularity of blockchain due to its potential to revolutionize various sectors. Sarmah emphasizes the irrefutable security of blockchain technology, a key advantage that has led to its adoption in addressing digital identity issues. However, for a more comprehensive review, it would be beneficial to explore the existing research on the challenges and limitations of blockchain adoption in various industries. Further research into scalability, interoperability, regulatory frameworks, and cost-effective implementation strategies is crucial for realizing the full potential of blockchain technology.

2.2 Bitcoin: A Peer-to-Peer Electronic Cash System- Satoshi Nakamoto (2008)

Satoshi Nakamoto's seminal paper, "Bitcoin: A Peer-to-Peer Electronic Cash System," published in 2008, laid the foundation for a revolutionary concept: a decentralized digital currency. This review explores the core tenets of Nakamoto's proposal and its potential impact on the financial landscape. Digital cash systems have long faced the challenge of double-spending, where the same unit of digital currency is used in multiple transactions. Traditional solutions rely on trusted third parties, like banks, to verify and record transactions. However, Nakamoto argues that this approach undermines the core advantages of digital cash, such as anonymity and censorship resistance. Nakamoto

proposes a novel solution using a peer-to-peer network and a cryptographically secure chain of blocks, later known as blockchain technology. Transactions are broadcast to the network, verified by participants (miners), and added to a permanent, tamper-proof public ledger. This distributed ledger eliminates the need for a central authority, ensuring transparency and immutability of transactions.

The paper introduces several critical technical innovations that underpin the Bitcoin network:

- **Proof-of-Work:** This consensus mechanism ensures the integrity and chronological order of transactions. Miners compete to solve complex mathematical puzzles, and the successful miner adds a new block of verified transactions to the blockchain. This process secures the network by making it computationally infeasible to tamper with past records.
- **Digital Signatures:** Cryptographic digital signatures allow users to prove ownership of Bitcoins and authorize transactions without revealing their private keys. This ensures secure and verifiable transactions without the need for trusted intermediaries.
- **Hashing:** Transactions are cryptographically hashed, creating a unique fingerprint that is linked to the previous block in the chain. This chaining process makes altering past records computationally impractical, as it would require modifying all subsequent blocks.

Nakamoto's paper has had a profound impact on the financial landscape. Bitcoin has become the most well-known cryptocurrency, inspiring the development of countless others. The core principles outlined in the paper – decentralization, immutability, and transparency – have fueled innovation in various sectors beyond finance. However, Bitcoin's design faces challenges, including scalability limitations, high energy consumption due to proof-of-work, and potential regulatory hurdles.

2.3 Blockchain technology in the maritime industry- Ivan Peronja, Kristijan Lenac, Roko Glavinović (2020)

The maritime sector is recognized as one of the most interconnected industries globally, involving the conveyance of a wide variety of commodities and records worldwide. Consequently, a significant volume of financial transactions and documentation exchanges occur daily to facilitate the movement of goods from one location to another.

The paper aims to explore the potential benefits of implementing blockchain technology in the maritime industry.It seeks to analyze the impact of blockchain on cost savings, efficiency, and environmental sustainability in maritime operations. The objective of this study is to demonstrate that the integration of blockchain technology can lead to savings in both time and financial resources. Specifically, the research outlines the historical expenses associated with container shipments and rates, while projecting potential future expenses and rates under a blockchain-oriented system. Moreover, a comparative analysis is conducted to evaluate the economic and temporal advantages of a "traditional" bill of lading in contrast to a blockchain-based bill of lading solution. The study finds that the implementation of blockchain technology in the maritime industry can lead to significant time and cost savings. Blockchain-based solutions offer a more secure, transparent, and efficient alternative to traditional processes like bill of lading in maritime transactions. The use of blockchain technology can streamline logistics, transport, and financial processes, resulting in substantial savings and reduced administrative burdens. It is crucial to highlight the potential environmental implications of blockchain technology in the maritime sector, particularly in reducing global paper consumption and emissions from vehicles. Lastly, the paper offers a detailed and comprehensive examination of the current and prospective applications of blockchain technology within the maritime domain.

2.4 Smart Logistics: Blockchain trends and applications- Yassine Issaouia et al.(2020)

This research paper by Yassine Issaouia et al. explores the convergence of blockchain technology and smart logistics, a cornerstone of Industry 4.0. The paper highlights the limitations of current logistics models burdened by data silos and centralized control. Blockchain, with its potential to revolutionize data management, emerges as a critical area of exploration.The authors acknowledge the widespread interest in blockchain but emphasize the scarcity of practical applications across industries. They attribute this to the inherent complexity of blockchain technology.

The core objective of the research is to bridge this gap by outlining various applications of blockchain in smart logistics and providing concrete examples within four key categories: Information, Transport, Finance, and Management. Blockchain's immutable ledger offers a secure and transparent platform for managing critical logistics

information. This can encompass data related to shipment tracking, inventory management, and documentation. The tamper-proof nature of blockchain ensures the authenticity and traceability of information, improving data integrity and streamlining information sharing between stakeholders.

The paper explores how blockchain can optimize transportation and logistics processes. Blockchain-based applications can track the movement of goods in real-time, enhancing visibility and facilitating informed decision-making. Smart contracts, a core blockchain feature, can automate key logistics milestones, such as triggering payments upon delivery confirmation. This can streamline operations and reduce administrative burdens.

The research highlights the potential of blockchain to improve financial management in logistics. Trade finance processes, often plagued by inefficiencies and paperwork, can be significantly streamlined through blockchain-based solutions. Smart contracts can automate trade finance processes, such as releasing payments upon fulfillment of pre-defined conditions. This can expedite transactions and reduce costs.

The paper explores how blockchain can enhance overall logistics management. Blockchain's secure data sharing capabilities can foster collaboration between different stakeholders involved in the supply chain. Additionally, blockchain can be used to create auditable records of maintenance logs and compliance documentation, ensuring transparency and accountability within logistics operations.

This research paper by Issaouia et al. presents a compelling argument for the transformative potential of blockchain technology in smart logistics. By outlining specific applications across information management, transport, finance, and logistics operations, the authors provide a roadmap for wider adoption of blockchain within the industry. The paper emphasizes the need to address the inherent complexity of blockchain and calls for further research to develop practical and scalable solutions for the smart logistics domain.

2.5 Application of blockchain technology in maritime logistics- Natalia Wagner, Bogusz Wiśnicki (2019)

This paper specifically investigates the burgeoning adoption of blockchain technology in maritime shipping, a sector traditionally burdened by inefficiencies and paper-based processes.

The research employs a two-pronged approach: web content analysis to gauge the overall interest and a multi-case study to delve into specific initiatives. The findings reveal a surge in blockchain-related projects undertaken by major container shipping companies, collectively representing a significant portion of global container capacity.

The paper identifies four primary drivers for blockchain development in maritime logistics:

- **Shipowner-led projects:** Major shipping companies are actively exploring and implementing blockchain solutions.
- **ICT provider initiatives:** Information and communication technology (ICT) providers are developing and offering blockchain-based platforms for the maritime industry.
- **Supply chain operator projects:** Logistics companies involved in the maritime supply chain are leveraging blockchain to improve efficiency across the entire network.
- **Dedicated consortia projects:** Collaborative efforts between industry stakeholders are fostering the development and adoption of standardized blockchain solutions.

The research further pinpoints key areas where blockchain technology is being tested or implemented within maritime logistics:

• **Contracting and documentation flow:** Streamlining processes like electronic bills of lading (eBLs) for faster trade cycles.
• **Smart contracts:** Automating key milestones and conditional payments based on predefined terms for improved efficiency.
• **Container/cargo track-and-trace:** Enabling real-time tracking of cargo movement for enhanced transparency and visibility.

- **Marine insurance:** Streamlining insurance processes and potentially reducing risks.
- **Ship register system:** Enhancing the security and efficiency of ship registration processes.
- **Bunker tracking system:** Ensuring the quality and origin of fuel used by vessels.
- **Crew certification system:** Securely managing and verifying crew credentials.

These findings offer valuable insights for maritime shipping companies and logistics operators. By understanding the potential benefits and various implementation models, industry players can make informed decisions about engaging in blockchain projects and selecting the approach that best aligns with their strategic goals.

2.6 Use of Blockchain-Based Smart Contracts in Logistics and Supply Chains - Mohammed Ali Alqarni et al. (2023)

The paper investigates the potential of blockchain technology, specifically blockchain-based smart contracts, to revolutionize logistics and supply chain management.The authors emphasize that blockchain offers several advantages, including enhanced transparency, immutability, security, and neutrality for all stakeholders involved in the supply chain. The paper explores the positive impact of blockchain on the social, environmental, and economic aspects of sustainability within supply chains.

One key benefit is the ability to combat counterfeiting by providing irrefutable proof of a product's provenance, from raw materials to the end consumer. This fosters consumer trust and protects intellectual property rights for manufacturers. The research delves into the implementation and operational aspects of smart contracts within blockchain technology. The authors explore their application in terrestrial, maritime, and aerial logistics networks. The paper acknowledges the challenges and opportunities associated with using smart contracts in logistics. These include issues related to implementation, deployment, auditing, and overall operational considerations.

This research paper sheds light on the transformative potential of blockchain technology and smart contracts for logistics and supply chain management. By promoting transparency, security, and sustainability, blockchain has the potential to significantly improve efficiency and trust within complex supply chain networks.

2.7 Blockchain technology in supply chain operations: Applications, challenges and research opportunities - Pankaj Dutta et al. (2020)

This paper reviews the potential of blockchain technology to transform supply chain (SC) operations. The authors examine 178 articles to assess the current state-of-the-art, applications, challenges, and future research opportunities. Blockchain's core features, such as decentralization, immutability, transparency, and security, make it a compelling solution for addressing inefficiencies and vulnerabilities in traditional SC management. The paper explores how blockchain can be applied across various industrial sectors. Provenance tracking enables the tracking of goods' origin and movement throughout the supply chain, particularly crucial in industries like food and pharmaceuticals to combat counterfeiting and ensure product integrity. Smart contracts automate key processes such as payments, approvals, and logistics management, streamlining workflows and enhancing efficiency. Real-time inventory management facilitated by blockchain provides organizations with accurate visibility into inventory levels, enabling optimization and reducing stockouts. Additionally, blockchain enhances visibility by providing all authorized participants with a shared view of transactions and data, fostering collaboration, trust, and traceability across the supply chain network.Despite its potential, blockchain integration in SC operations faces several challenges. The authors identify some of the key hurdles as:

- ✓ Scalability and Interoperability
- ✓ Standardization and Regulation
- ✓ Integration Costs and Technical Expertise**.**
- ✓ Security Concerns

The paper concludes by outlining a future research agenda to address the identified challenges and propel further development of blockchain-based SC solutions.

2.8 Blockchain-enabled supply chain: analysis, challenges, and future directions- Jabbar et al. (2020)

This research paper explores the potential of blockchain technology in revolutionizing supply chain management. The core challenge addressed is ensuring data integrity and product provenance within complex, multi-stakeholder supply chains. Traditional solutions often suffer from fragmented data, unreliable tracking, and inconsistent protocols across different actors. Blockchain emerges as a promising solution due to its ability to provide secure traceability, control, and trust creation among stakeholders in a cost-effective manner.

The paper positions itself as the first comprehensive survey on the challenges and future directions of blockchain-enabled supply chains. It delves into the existing state of supply chain digitalization, highlighting the role of GS1 standards and technologies. Existing use cases and startups leveraging blockchain in this domain are reviewed and presented in a structured format.

Following this background, the authors critically analyze the technical and non-technical challenges hindering the widespread adoption of blockchain in supply chains. The suitability of various consensus algorithms for different supply chain applications is also explored. The paper then dissects the tools and technologies that comprise the blockchain ecosystem.

To pave the way for mass adoption, the authors identify key areas for future research. Finally, they propose MOHBSChain, a novel framework specifically designed for blockchain-enabled supply chains.

The paper provides a comprehensive overview of the current landscape, analyzes existing limitations, and proposes future research directions and a novel framework to advance the field.

2.9 Blockchain for and in Logistics: What to Adopt and Where to Start- Dobrovnik et al. (2018)

The paper investigates the potential of blockchain technology in the logistics industry. It highlights the gap in existing research, which often fails to distinguish between what

aspects of blockchain to adopt and where to identify the most suitable business opportunities for its implementation. To address this gap, the authors propose a two-pronged approach. First, they leverage Rogers' (2003) "attributes of innovation framework" to identify potential applications of blockchain in logistics. Second, they introduce a framework outlining four transformation phases, which categorize these applications based on their impact on organizational structures and processes.

By combining these frameworks, the paper aims to equip logistics managers with a systematic approach for assessing blockchain opportunities. This allows them to make informed decisions about where to initiate building organizational capabilities for successful adoption and deployment of blockchain technology.

The research contributes to the field by providing a structured framework to guide logistics companies in their exploration and implementation of blockchain-based solutions.

2.10 Review of studies of blockchain technology effects on the shipping industry Kelly Gerakoudi-Ventouri (2022)

The paper highlights the challenges faced by the maritime sector in decision-making. Traditional processes are often time-consuming and complex due to the paper-intensive nature of the industry and the lack of transparency in information sharing. This resonates with existing research by Jović et al. (2019) who emphasize the potential of blockchain for secure and efficient data distribution, a key factor in streamlining shipping logistics and decision-making.

Gerakoudi-Ventouri (2022) employs grounded theory, a qualitative research methodology, to explore how blockchain can transform decision-making. This approach aligns with the need for in-depth qualitative studies highlighted by Pu and Lam (2021) who point out the scarcity of research on how blockchain specifically influences decision-making in the shipping industry.

The study's findings suggest that the core features of blockchain technology – instant and reliable data sharing – hold immense potential for the shipping industry. By creating a secure and transparent record of transactions and cargo movement, blockchain can

empower stakeholders with real-time information, facilitating more informed and efficient decision-making. This aligns with the broader literature on blockchain in maritime shipping, where studies by Yang et al. (2019) point towards improved visibility across the supply chain, allowing for better-informed decisions .

By focusing on the decision-making aspect, the study offers a valuable perspective on how this technology can address a critical challenge faced by the industry. However, further research is needed to explore the practical implications of these findings. This could involve investigating specific use cases of blockchain in decision-making scenarios within the maritime sector. Additionally, exploring the potential challenges associated with implementing blockchain for decision-making, such as user adoption and integration with existing systems, would provide a more comprehensive understanding of its feasibility.

2.11 Improving shipping contracts with the use of Blockchains- Harshvardhan

This research paper investigates the potential of blockchain technology to streamline the contracting process between charterers and shipowners in the liquid bulk ocean shipping market. The core focus lies on enhancing efficiency in terms of time and cost savings.
This study centers on the agreement between a charterer and a ship-owner within the liquid bulk ocean shipping sector. The primary inquiry revolves around exploring the potential of emerging technologies, particularly Blockchain, in enhancing the efficiency of the contracting process in terms of time and cost. The paper reveals the feasibility of significant time and cost reductions in specific areas. However, challenges persist, particularly in negotiations, which may necessitate waiting for further advancements in technology to address them effectively.

2.12 Assessing Blockchain Technology application for freight booking business: a case study from Technology Acceptance Model perspective -Wee Kwan Albert Tan, Balan Sundarakani (2020)

This research paper investigates the potential of blockchain technology to improve the efficiency of freight booking processes in the context of a global shipping company offering freight consolidation services. The core objective is to evaluate how blockchain can enhance competitiveness and sustainability within the freight booking domain. The study leverages the Technology Acceptance Model (TAM) to understand the factors influencing a company's decision to adopt blockchain technology. TAM posits that

perceived usefulness and perceived ease of use are key determinants of technology adoption. The research employs an inductive case study approach, focusing on a specific global shipping company offering freight consolidation services. This approach allows for an in-depth examination of the challenges faced by the company and how blockchain technology can potentially address them. The research acknowledges the inefficiencies plaguing current practices and explores how blockchain can enhance competitiveness and sustainability.

The review of existing literature supports the concept of blockchain for improving freight booking efficiency. Decentralization, immutability, and transparency offered by blockchain can address challenges like paper-based documentation and communication bottlenecks.

CHAPTER III

BLOCKCHAIN AND SMART CONTRACT

3.1 Blockchain Overview

Blockchain technology has garnered significant attention across various sectors due to its unique features such as decentralization, security, reliability, and data integrity [7]. In the financial field, blockchain technology has shown promising application prospects[8]. Research indicates that blockchain technology has the potential to enhance the efficiency and security of supply chain finance models due to its characteristics of decentralization, immutability, and the absence of third parties (Xie & Li, 2021). Furthermore, studies have explored the applications of blockchain technology in healthcare, focusing on disease information dissemination prevention, risk management methods, and medical waste management (Agbo et al., 2019; Yang et al., 2022; Kassou et al., 2021). The education sector has also been a focal point for blockchain technology exploration. Research has examined the use of blockchain in education management, discussing both present and future applications (Bhaskar et al., 2020). Additionally, studies have aimed to understand the potential applications of blockchain technology in education systems, emphasizing its role in improving security and data integrity[9] (Chen et al., 2018). The exploration of blockchain technology in the education sector extends to specific regions like the ltanate of Oman, where researchers have investigated its implementation and impact[10]. In the realm of security, a survey on the security of blockchain systems highlighted the importance of addressing security challenges associated with blockchain technology (Li et al., 2020). Moreover, the applicability of blockchain technology in securities settlement has been assessed, indicating its potential to streamline settlement processes in the financial sector (Bauvars, 2021). Research on blockchain technology has

[7] Alammary, A., Alhazmi, S., Almasri, M., & Gillani, S. (2019). Blockchain-based applications in education: a systematic review. Applied Sciences, 9(12), 2400. https://doi.org/10.3390/app9122400

[8] Zhang, W. (2022). The current situation and trend of blockchain technology in the financial field. Mobile Information Systems, 2022, 1-13. https://doi.org/10.1155/2022/7908625

[9] Chen, G., Xu, B., Lu, M., & Chen, N. (2018). Exploring blockchain technology and its potential applications for education. Smart Learning Environments, 5(1). https://doi.org/10.1186/s40561-017-0050-x

[10] Younas, A. and Wahaibi, M. (2023). Exploration of blockchain technology in the education sector in the sultanate of oman. International Journal of Academic Research in Business and Social Sciences, 13(4). https://doi.org/10.6007/ijarbss/v13-i4/15889

also delved into cross-chain interaction models, hybrid intrusion detection systems, and the utilization of blockchain as a database engine in accounting systems. These studies underscore the versatility of blockchain technology and its capacity to revolutionize various industries through enhanced security, transparency, and efficiency.

3.2 History of Blockchain

Blockchain technology has emerged as a revolutionary concept with far-reaching implications across various sectors. The history of blockchain can be traced back to the introduction of the first cryptocurrency, Bitcoin, by an anonymous entity known as Satoshi Nakamoto in a white paper in 2008. Nakamoto's groundbreaking proposal outlined a decentralized system for electronic transactions that did not rely on trust but instead utilized digital signatures within a peer-to-peer network, employing proof-of-work to maintain a transparent public ledger of transactions[11]. This marked the inception of blockchain technology, which serves as the underlying framework for cryptocurrencies and a myriad of other applications.

The core concept behind blockchain technology was initially conceived as a means to develop cryptographic certificates in the form of an immutable public ledger (Ishmaev, 2017). Over time, this concept evolved to encompass a ledger of monetary transactions, leading to the creation of the Bitcoin protocol and the subsequent proliferation of cryptocurrencies. The fundamental innovation of blockchain lies in its ability to provide a secure, transparent, and decentralized platform for recording transactions and maintaining a verifiable history of data[12]. Blockchain technology operates on the principle of a distributed ledger, which ensures that all participants in the network have access to a shared, immutable record of transactions. This ledger serves as a transparent repository of information, enabling secure data storage and facilitating trustless interactions among network participants. The decentralized nature of blockchain eliminates the need for a central authority, allowing for peer-to-peer transactions and

[11] Tagliafico, A., Campi, C., Bignotti, B., Bortolotto, C., Buccicardi, D., Coppola, F., … & Faggioni, L. (2022). Blockchain in radiology research and clinical practice: current trends and future directions. La Radiologia Medica, 127(4), 391-397. https://doi.org/10.1007/s11547-022-01460-

[12] Dubovitskaya, A., Baig, F., Xu, Z., Shukla, R., Zambani, P., Swaminathan, A., … & Wang, F. (2020). Action-ehr: patient-centric blockchain-based electronic health record data management for cancer care. Journal of Medical Internet Research, 22(8), e13598. https://doi.org/10.2196/13598

enhancing the security and integrity of data exchanges. The evolution of blockchain technology has been accompanied by a diversification of its applications across various domains. From its origins in cryptocurrency, blockchain has expanded to encompass fields such as healthcare, supply chain management, finance, and real estate. The versatility of blockchain lies in its ability to provide secure and transparent data management solutions, enabling enhanced traceability, security, and efficiency in diverse operational contexts[13]. One of the key features of blockchain technology is its capacity to ensure the integrity and authenticity of data through cryptographic mechanisms. By leveraging advanced encryption techniques, blockchain networks can safeguard sensitive information and verify the validity of transactions, thereby enhancing data security and privacy. This aspect of blockchain technology has made it a valuable asset in sectors where data confidentiality and trust are paramount, such as healthcare and finance[14].

Moreover, blockchain technology has been heralded as a tool for promoting transparency and accountability in governance systems, particularly in the context of smart cities . The immutable nature of blockchain records, coupled with its decentralized architecture, offers a robust framework for combating corruption and enhancing public trust in governmental processes. By leveraging blockchain as an anti-corruption tool, smart cities can establish a foundation for transparent and efficient governance practices.

The history of blockchain technology is a testament to its transformative potential and enduring impact on various industries. From its humble beginnings as the foundation of cryptocurrencies to its current role as a catalyst for innovation in data management and governance, blockchain has reshaped the digital landscape. As blockchain continues to evolve and find new applications, its foundational principles of decentralization, transparency, and security will continue to drive advancements in technology and redefine the way we interact with data and information

[13] Dietrich, F., Louw, L., & Palm, D. (2023). Blockchain-based traceability architecture for mapping object-related supply chain events. Sensors, 23(3), 1410. https://doi.org/10.3390/s23031410

[14] Kaur, H., Jameel, R., Alam, M., Alankar, B., & Chang, V. (2023). Securing and managing healthcare data generated by intelligent blockchain systems on cloud networks through dna cryptography. Journal of Enterprise Information Management, 36(4), 861-878. https://doi.org/10.1108/jeim-02-2021-0084

3.3 How does blockchain work

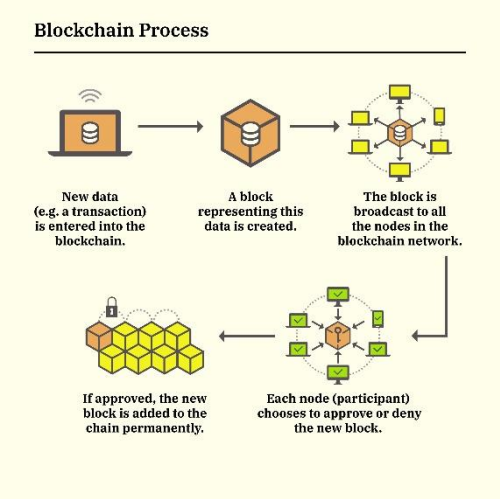

Figure 1. Blockchain working process. Source:money.com

Blockchain technology has emerged as a transformative innovation with the potential to revolutionize various industries by providing a secure, transparent, and decentralized platform for recording transactions and managing data. At its core, blockchain operates on the principle of a distributed ledger, ensuring that all participants in the network have access to a shared, immutable record of transactions[15]. This decentralized consensus mechanism is fundamental to guaranteeing the reliability and consistency of data and transactions within the blockchain network.

The development history of blockchain technology is characterized by a series of key advancements in its structure, consensus mechanisms, and applications. Initially conceived as a means to develop cryptographic certificates in the form of an immutable public ledger, blockchain evolved to encompass a ledger of monetary transactions, leading to the creation of the Bitcoin protocol and the subsequent proliferation of cryptocurrencies (Xiao et al., 2020). The transaction and ledger structure of blockchain systems, along with the consensus mechanisms, play a crucial role in ensuring the integrity and security of data exchanges within the network (Xiao et al., 2020).

One of the defining features of blockchain technology is its ability to provide real-time transparency and cost savings in various industries, including manufacturing, finance,

[15] LI, X. (2022). A blockchain-based verifiable user data access control policy for secured cloud data storage. Computational Intelligence and Neuroscience, 2022, 1-12. https://doi.org/10.1155/2022/2254411

and supply chains [16]. By leveraging blockchain technology, organizations can enhance operational efficiency, traceability, and security while reducing costs associated with traditional data management systems. The transparency enabled by blockchain systems allows for greater accountability and trust among network participants, leading to improved business processes and decision-making (Ko et al., 2018).

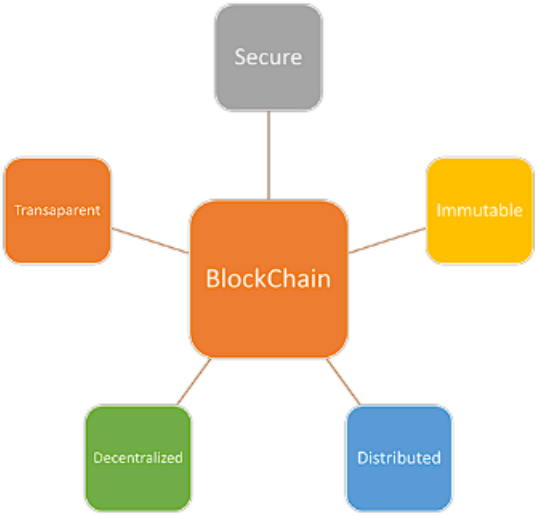

Figure 2. Characteristics of Blockchain, Source:. https://doi.org/10.3390/electronics12061340

From a transaction cost economics perspective, blockchain technology's utility lies in its ability to reduce and manage transactions efficiently, thereby driving its applicability in diverse institutional frameworks (Ahluwalia et al., 2020). By minimizing transaction costs and streamlining processes, blockchain facilitates secure and efficient data management, making it an attractive solution for startups, financial institutions, and various other sectors seeking to optimize their operations (Ahluwalia et al., 2020).

The security and integrity of blockchain systems are further reinforced by the cryptographic techniques and consensus mechanisms employed within the network. Blockchain systems utilize advanced encryption methods, such as cryptographic hash functions and asymmetric-key cryptography, to safeguard sensitive information and verify the validity of transactions (Yaga et al., 2018). The consensus mechanisms, including proof of work, proof of stake, and proof of authority, play a crucial role in maintaining data consistency and operational synchronization between nodes in the blockchain network (Wang et al., 2020). Moreover, blockchain technology has been instrumental in promoting transparency and accountability in governance systems,

[16] Ko, T., Lee, J., & Ryu, D. (2018). Blockchain technology and manufacturing industry: real-time transparency and cost savings. Sustainability, 10(11), 4274. https://doi.org/10.3390/su10114274

particularly in the context of smart cities. The immutable nature of blockchain records, coupled with its decentralized architecture, offers a robust framework for combating corruption and enhancing public trust in governmental processes. The operational mechanisms of enterprise blockchain digital systems (BDS) are designed to meet industry-specific needs and ensure the security and functionality of the system. The model framework of BDS is based on industry requirements and incorporates multiple levels of functionality to support various operations within the network (Su & Wang, 2022). By analyzing the functions and operating mechanisms of each level of the system, organizations can tailor their blockchain solutions to optimize performance and meet specific business objectives (Su & Wang, 2022).

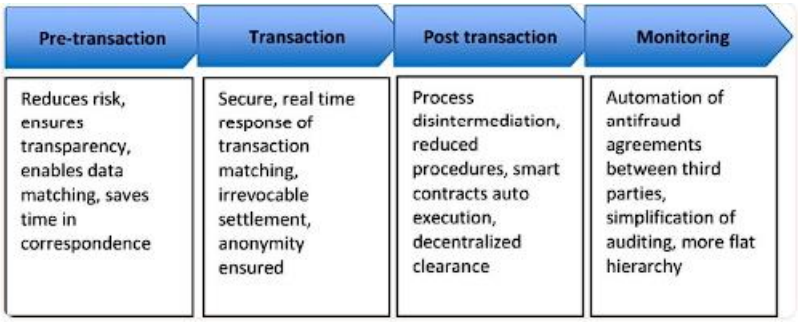

Figure 3. Blockchain-supported transaction journey,
Source:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7522652/

Blockchain technology represents a paradigm shift in data management and transaction processing, offering a decentralized, secure, and transparent platform for a wide range of applications. By leveraging cryptographic techniques, consensus mechanisms, and advanced data management systems, blockchain enables organizations to enhance operational efficiency, data security, and trust among network participants. As blockchain technology continues to evolve and find new applications, its foundational principles of decentralization, transparency, and security will continue to drive advancements in technology and redefine the way businesses interact with data and information.

3.3.1 Tiers of Blockchain

Blockchain technology has evolved through various versions, commonly referred to as Blockchain 1.0, 2.0, 3.0, and 4.0, each introducing new features and capabilities.

Blockchain 1.0, the initial version, is primarily associated with the creation of Bitcoin and its underlying technology. It focused on enabling peer-to-peer transactions through a

decentralized and immutable ledger. This version laid the foundation for the subsequent developments in blockchain technology (Ghiro et al., 2021).

Blockchain 2.0 brought smart contracts to the forefront, with platforms like Ethereum allowing for programmable transactions and decentralized applications (DApps). Smart contracts are self-executing contracts with the terms of the agreement directly written into code, enabling automated and trustless interactions (Qian et al., 2022).

Blockchain 3.0 aimed to address scalability and interoperability issues. This version introduced solutions like Proof of Stake (PoS) consensus mechanisms, which are more energy-efficient compared to the Proof of Work (PoW) used in earlier versions. PoS blockchains select validators based on the number of coins they hold, promoting a more sustainable approach to securing the network (Ferreira, 2021).

Blockchain 4.0 is characterized by advancements in privacy, security, and governance. This version integrates blockchain with other emerging technologies like the Internet of Things (IoT) and artificial intelligence to create more robust and versatile systems. It focuses on enhancing data privacy and security while improving the governance structures of blockchain networks (Bhatia et al., 2021).

The evolution of blockchain technology has also found applications in various industries. For instance, in the manufacturing industry, blockchain enables real-time transparency and cost savings by providing a secure and transparent way to track transactions and supply chain activities (Ko et al., 2018). In the financial sector, blockchain has revolutionized processes by offering decentralized consensus mechanisms that enhance security and transparency (Cong, 2018). Additionally, blockchain has been leveraged in fields like construction management to improve information accountability and efficiency (Yang et al., 2022).

As blockchain continues to evolve, researchers are exploring innovative solutions to enhance its capabilities. For example, the integration of blockchain with IoT in healthcare applications promises increased data transparency, security, and efficiency in service delivery (Bhatia et al., 2021). Moreover, decentralized models for digital rights management are being developed to address copyright issues and improve data sharing practices (Zhang et al., 2020). The evolution of blockchain from version 1.0 to 4.0 signifies a progression towards more efficient, secure, and versatile systems. Each version has introduced new features and addressed existing challenges, paving the way for the widespread adoption of blockchain technology across various sectors.

3.3.2 Types of Blockchain

Blockchain technology encompasses various types, each serving distinct functions and applications. Understanding these different types is crucial for grasping the technology's potential across industries and scenarios. The main categories of blockchains include public blockchains, private blockchains, consortium blockchains, permissionless blockchains, and permissioned blockchains.

1. Public Blockchains: Public blockchains are decentralized networks open to anyone for participation, transaction viewing, and validation without requiring permission. Examples of public blockchains are Bitcoin and Ethereum. They offer transparency, security, and immutability, making them suitable for applications emphasizing trust and decentralization (Tovanich et al., 2021).

2. Private Blockchains: Private blockchains are restricted networks where only authorized entities can engage. Typically used within organizations, they enhance security and streamline operations by providing more control over access and permissions compared to public blockchains. Private blockchains are suitable for scenarios prioritizing privacy and data control (Ra et al., 2020).

3. Consortium Blockchains: Consortium blockchains represent a hybrid model between public and private blockchains. In this setup, a group of organizations collaborates to maintain the network. Consortium blockchains strike a balance between decentralization and control, making them ideal for industries requiring secure data sharing and collaboration among multiple stakeholders (Ra et al., 2020).

4. Permissionless Blockchains: Permissionless blockchains, like Bitcoin, enable anyone to join the network, participate in transaction validation, and contribute to the consensus process. These blockchains are fully decentralized and do not necessitate permission for access or use. They prioritize openness and inclusivity, allowing anyone to engage with the network (Liu & Xu, 2019).

5. Permissioned Blockchains: Permissioned blockchains restrict access to authorized participants exclusively. Commonly deployed in enterprise settings, they offer enhanced privacy, scalability, and efficiency compared to permissionless blockchains. Permissioned blockchains are suitable for applications demanding a higher level of governance and regulatory compliance (Liu & Xu, 2019).

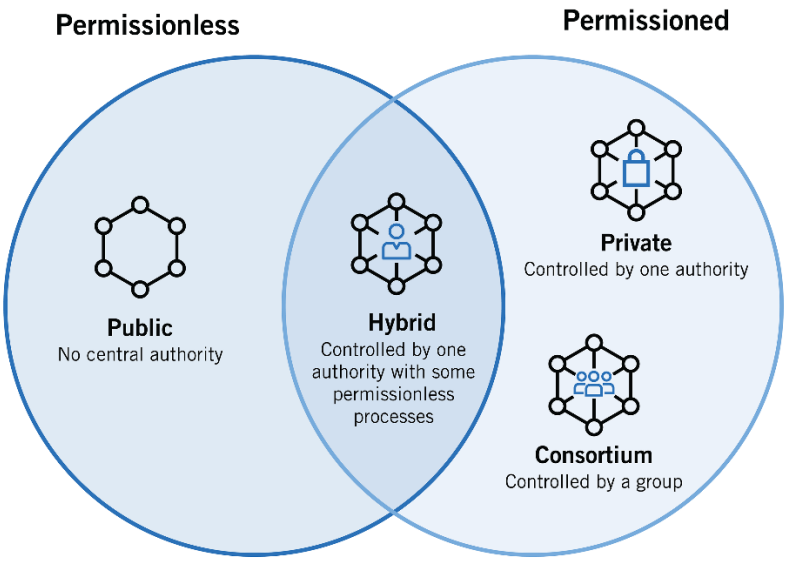

Figure 4, Permissioned and Permissionless Blockchain. Source:https://www.jdsupra.com/legalnews/types-of-blockchain-public-private-or-5282575/

Each type of blockchain has its strengths and weaknesses, catering to different use cases. Public blockchains excel in scenarios requiring transparency and decentralization, such as cryptocurrency transactions and decentralized applications. Private blockchains suit organizations valuing data privacy and control. Consortium blockchains are well-suited for industries necessitating collaboration among multiple entities while maintaining a level of control. Permissionless blockchains emphasize openness and inclusivity, whereas permissioned blockchains provide heightened security and governance. Understanding the characteristics and functionalities of each blockchain type empowers organizations and developers to select the most suitable blockchain solution for their specific needs, whether in finance, supply chain management, healthcare, or any other industry

3.4 Blockchain industrial use

Blockchain technology, originally associated with cryptocurrencies, has evolved to revolutionize various industries by enhancing transparency, security, and efficiency in business operations. This article explores the diverse industrial use cases of blockchain technology and how it is reshaping traditional processes to usher in a new era of digital innovation.

1. Supply Chain Management: Blockchain technology plays a crucial role in supply chain management by offering enhanced traceability and transparency. Its decentralized

and immutable ledger capabilities allow stakeholders to track products from origin to consumer, reducing fraud and inefficiencies[17] Cole et al. (2019).

2. Banking and Financial Services: The banking and financial services sector has embraced blockchain technology to streamline operations and improve security. Blockchain applications enable faster and more secure transactions, reduce costs, and automate contract execution through smart contracts (Guo & Liang, 2016).

3. Corporate Governance: Blockchain technology has the potential to transform corporate governance by providing transparent and tamper-proof records of activities. Organizations can enhance accountability and compliance by leveraging blockchain for governance processes, including automating voting through smart contracts (Beck et al., 2018).

4. Healthcare Industry: In healthcare, blockchain technology secures electronic health records, promotes interoperability among providers, and ensures patient data privacy. Storing medical records on a blockchain enhances data security, confidentiality, and information exchange, ultimately improving patient care (Mayer et al., 2019).

5. Media and Entertainment: Blockchain technology is increasingly utilized in the media and entertainment industry for rights management and content distribution. Content creators leverage blockchain for digital rights management, ensuring intellectual property protection and fair compensation through automated royalty payments via smart contracts (Peng et al., 2022).

6. Energy and Utilities: The energy and utilities sector explores blockchain technology for optimizing energy trading, grid management, and renewable energy integration. Blockchain-enabled platforms facilitate peer-to-peer energy trading and automate transactions through smart contracts, fostering trust among market participants[18] (Zehir, 2022).

7. Manufacturing and Industry 4.0: In manufacturing, blockchain technology drives innovation in Industry 4.0 initiatives by enabling secure data sharing, supply chain optimization, and product authentication. Companies use blockchain to ensure product

[17] Cole, R., Stevenson, M., & Aitken, J. (2019). Blockchain technology: implications for operations and supply chain management. Supply Chain Management an International Journal, 24(4), 469-483. https://doi.org/10.1108/scm-09-2018-0309

[18] Zehir, C. (2022). Identification of suitable blockchain solutions for promising natural gas use cases.. https://doi.org/10.15405/epsbs.2022.12.02.8

provenance, quality control, and compliance, while smart contracts automate processes and enhance data visibility (Panarello et al., 2018).

The industrial use of blockchain technology is reshaping business models across sectors, offering benefits such as transparency, security, and efficiency. From improving supply chain operations to transforming financial transactions, healthcare management, and corporate governance, blockchain technology continues to drive innovation and redefine the future of business.

3.5 Smart contracts

In today's digital world, agreements and contracts play a crucial role in facilitating secure and efficient transactions. However, traditional paper-based contracts often suffer from inefficiencies and limitations. Smart contracts have emerged as a transformative application of blockchain technology, revolutionizing the way agreements are executed and enforced.

3.5.1 Understanding Smart Contracts

Imagine a contract that can automatically execute its terms and conditions upon meeting predetermined criteria. This is the essence of a smart contract. Smart contracts are self-executing contracts with predefined rules and conditions encoded in code. They operate on blockchain networks, enabling automated and trustless execution of agreements. Smart contracts eliminate the need for intermediaries, enhancing transparency, security, and efficiency in transactions[19] Zheng et al. (2020). The code defines the terms of the agreement and automatically executes the actions specified within it when certain conditions are fulfilled.

1. Technology Behind Smart Contracts: Smart contracts leverage blockchain technology to ensure secure and decentralized execution of agreements. They are embedded in blockchains, enabling the automatic enforcement of contractual terms without the intervention of a trusted third party. Smart contracts are decentralized,

[19] Zheng, Z., Xie, S., Dai, H., Chen, W., Chen, X., Weng, J., … & Imran, M. (2020). An overview on smart contracts: challenges, advances and platforms. Future Generation Computer Systems, 105, 475-491. https://doi.org/10.1016/j.future.2019.12.019

autonomous, and tamper-proof, providing a reliable framework for executing transactions[20] (Hu et al., 2021).

2. How Smart Contracts Work: Smart contracts operate based on predefined conditions and actions encoded in their code. When specific conditions are met, the contract automatically executes the agreed-upon actions. Transactions conducted through smart contracts are recorded on the blockchain, ensuring transparency, auditability, and immutability. Once deployed, smart contracts cannot be altered, enhancing security and trust in transactions[21] (Hewa et al., 2021).

3. Key Characteristics of Smart Contracts:

Self-Executing: Smart contracts eliminate the need for manual intervention and third-party enforcement. Once deployed on a blockchain, the code executes automatically when predetermined conditions are met.

Transparent and Immutable: Like the blockchain itself, smart contracts are transparent and immutable. All participants can access the code, ensuring clarity and preventing unauthorized alterations.

Secure: Cryptographic algorithms used in blockchain technology guarantee the security and integrity of smart contracts, minimizing the risk of fraud or manipulation.

Trustless: Smart contracts foster trust among parties by relying on pre-defined code and automated execution, eliminating the need for a central authority.

[20] Hu, B., Zhang, Z., Liu, J., Liu, Y., Yin, J., Lu, R., … & Lin, X. (2021). A comprehensive survey on smart contract construction and execution: paradigms, tools, and systems. Patterns, 2(2), 100179. https://doi.org/10.1016/j.patter.2020.100179

[21] Hewa, T., Ylianttila, M., & Liyanage, M. (2021). Survey on blockchain based smart contracts: applications, opportunities and challenges. Journal of Network and Computer Applications, 177, 102857. https://doi.org/10.1016/j.jnca.2020.102857

Figure 5:Charecteristics of Smart Contracts. Source:https://doi.org/10.3390/electronics12061340

3.5.2 Use Cases of Smart Contracts:

1. Supply Chain Management: Smart contracts streamline supply chain processes by automating tasks such as inventory tracking, payment settlements, and logistics management. They enhance transparency, traceability, and efficiency in supply chain operations, reducing fraud and errors[22] (Tian & Chen, 2022).

2. Financial Services: In the financial sector, smart contracts facilitate peer-to-peer transactions, loan disbursements, and asset transfers. They enable secure and efficient financial operations, reducing costs and processing times while ensuring compliance with regulations (Capocasale & Perboli, 2022).

3. Healthcare Industry: Smart contracts enhance data security and interoperability in healthcare by securely managing patient records, insurance claims, and medical billing. They improve data accuracy, privacy, and accessibility, leading to better patient care outcomes (Xiong & Hu, 2022).

4. Legal Contracts: Smart contracts are increasingly used in legal agreements, automating contract execution, dispute resolution, and compliance monitoring. They

[22] Tian, M. and Chen, J. (2022). Smart contract in blockchain., 868-875. https://doi.org/10.2991/978-94-6463-030-5_86

provide a secure and transparent way to enforce contractual terms and conditions (Negara et al., 2021).

5. Real Estate Transactions: Smart contracts revolutionize real estate transactions by automating property transfers, escrow services, and rental agreements. They streamline the buying and selling process, reducing paperwork and transaction costs[23] (Rustiana et al., 2022).

3.5.3 Challenges and Future Directions

While smart contracts offer numerous benefits, challenges such as security vulnerabilities, legal complexities, and scalability issues persist. Future research aims to address these challenges, enhance smart contract functionality, and expand their applications in emerging fields like decentralized finance (DeFi), governance, and digital identity. Smart contracts represent a significant advancement in contract execution, offering a secure, efficient, and transparent way to conduct transactions. Their versatility and potential to transform various industries make them a cornerstone of blockchain technology, paving the way for a more automated and decentralized future of business operations.

Figure 6, Smart contract Challenges. Source:https://doi.org/10.1007/s12083-021-01127-0

[23] Rustiana, D., Ramadhan, D., Wibowo, L., & Nugroho, A. (2022). State of the art blockchain enabled smart contract applications in the university. Blockchain Frontier Technology, 2(2), 70-80. https://doi.org/10.34306/bfront.v2i2.229

CHAPTER IV
CHALLENGES SURROUNDING BLOCKCHAIN IN THE MARITIME SECTOR

4.1 Shipment tracking

4.1.1 Identifying problems associated with current shipment tracking procedures

In the maritime industry, transactions are typically expensive, time-consuming, and slow. The shipping sector is largely dependent on conventional business practices, such as the use of physical documents and paperwork that is utilised by a number of different supply chain participants.Shipment tracking in container shipping plays a crucial role in ensuring the efficient movement of goods. The current shipment tracking processes in container shipping face several difficulties. These include manual data entry leading to errors, delays in updating shipment statuses, lack of real-time visibility, disputes over shipment conditions, and difficulties in tracking multiple shipments simultaneously. Additionally, the reliance on paper-based documentation makes it challenging to maintain accurate and up-to-date records, impacting operational efficiency and customer satisfaction creating difficulties for various stakeholders, and ultimately impacting the entire ecosystem.

1. **Lack of Real-Time Visibility:**
    - Current shipment tracking processes often rely on manual updates and periodic check-ins, leading to delays in obtaining real-time information about cargo location and status.
    - Without real-time visibility, stakeholders such as shippers, carriers, and consignees face challenges in planning and decision-making, resulting in inefficiencies and potential disruptions in supply chain operations.
2. **Fragmented Systems and Data Silos:**
    - The container shipping industry involves multiple stakeholders, each maintaining separate systems and databases for tracking shipments.
    - Fragmentation and data silos hinder seamless communication and data sharing among stakeholders, leading to information asymmetry, duplication of efforts, and inconsistencies in tracking data.
3. **Inaccurate or Incomplete Information:**

- Manual data entry and reliance on paper-based documentation increase the likelihood of errors and inaccuracies in tracking information.
- Incomplete or inconsistent data across different tracking systems further exacerbate the problem, making it challenging to obtain a comprehensive view of cargo movements and status.

4. **Limited Transparency and Trust:**
    - Lack of transparency in shipment tracking processes can erode trust among stakeholders, leading to disputes, delays, and increased costs.
    - Without visibility into the entire supply chain, parties may face difficulties in verifying the accuracy of tracking information and ensuring compliance with contractual agreements.
5. **Manual Interventions and Paperwork:**
    - Traditional shipment tracking processes involve manual interventions and extensive paperwork, leading to administrative burdens, delays, and increased operational costs.
    - Manual handling of documents such as bills of lading, certificates of origin, and customs declarations can introduce errors, delays in processing, and potential for fraud.
6. **Limited Interoperability and Integration:**
    - The lack of standardized tracking protocols and interoperability among different tracking systems hampers seamless integration and data exchange.
    - Integration challenges between legacy systems and emerging technologies hinder efforts to modernize tracking processes and leverage advanced analytics for predictive insights.

The challenges in shipment tracking processes have a significant impact on efficiency at various levels in maritime trade. Delays in updating shipment statuses can lead to disruptions in supply chain operations, affecting delivery schedules and customer satisfaction. Disputes over shipment conditions can result in additional costs, legal issues, and damaged relationships with stakeholders. Lack of transparency and real-time visibility hinders decision-making and planning, leading to inefficiencies in resource allocation and operational management.

4.1.2 Impact on Efficiency at Various Levels in Maritime Trade

1. **Operational Efficiency:**
    - Inefficient shipment tracking processes result in delays, miscommunications, and suboptimal resource utilization, leading to decreased operational efficiency at ports, terminals, and logistics facilities.
    - Lack of real-time visibility and fragmented data systems hinder effective resource planning, vessel scheduling, and terminal operations, contributing to congestion and delays in cargo handling.
2. **Customer Service and Satisfaction:**
    - Poor tracking accuracy and limited transparency can undermine customer satisfaction, as shippers and consignees experience delays, uncertainty, and difficulties in tracking their shipments.
    - Inaccurate or incomplete tracking information may lead to customer complaints, disputes, and reputational damage for shipping companies and logistics providers.
3. **Financial Performance:**
    - Inefficiencies in shipment tracking processes result in increased operating costs, including labor expenses, administrative overheads, and penalties for delays or errors.
    - Disruptions in supply chain operations due to tracking inaccuracies or delays may result in financial losses, contractual liabilities, and missed business opportunities for stakeholders across the maritime trade ecosystem.
4. **Risk Management and Compliance:**
    - Inadequate tracking capabilities pose risks related to cargo security, theft, loss, or damage during transit, exposing stakeholders to financial and reputational risks.
    - Compliance with regulatory requirements, such as customs clearance procedures, trade documentation, and security mandates, becomes challenging without accurate and timely tracking information, leading to potential fines, penalties, and operational disruptions.

5. **Competitive Advantage and Market Positioning:**
    - Shipping companies and logistics providers that can offer superior tracking capabilities, real-time visibility, and proactive communication with customers gain a competitive edge in the market.
    - Inefficient tracking processes and poor data quality may erode competitive advantage, as customers prioritize reliability, transparency, and efficiency in their choice of service providers.

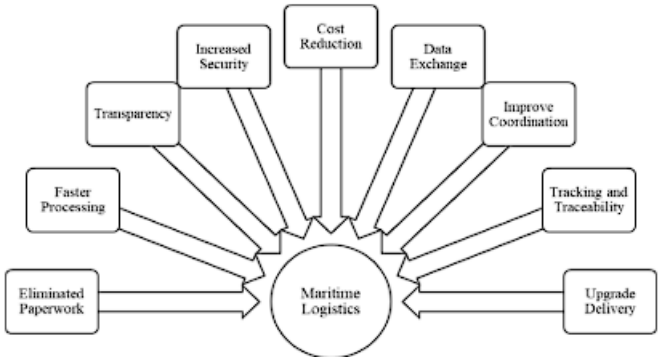

Figure 7: Ways in which Blockchain affects maritime trade. Source: https://doi.org/10.22059/jitm.2022.87846

The challenges in shipment tracking processes in container shipping impact efficiency in maritime trade. Efficient shipment tracking processes are essential for optimizing operations, enhancing customer satisfaction, and maintaining competitiveness in the maritime trade industry. Addressing the challenges associated with current tracking processes requires investments in technology, standardization of data protocols, and collaboration among stakeholders to improve visibility, transparency, and trust across the supply chain.

4.1.3 How Blockchain Assists Efficient Shipment Tracking

Blockchain technology offers numerous advantages in revolutionizing shipment tracking processes. By leveraging blockchain for tracking, smart contracts can automate agreement execution, update shipment statuses in real time, and trigger actions based on predefined conditions. Blockchain ensures data integrity, transparency, and security, thereby reducing the risk of disputes and errors. The decentralized nature of blockchain allows stakeholders to access real-time information, enhancing visibility and trust in the tracking process. Here's how blockchain addresses the challenges mentioned above:

1. **Immutable Ledger:** Blockchain provides an immutable ledger where all transactions related to shipment tracking are recorded in chronological order. Once recorded, data cannot be altered or tampered with, ensuring data integrity and trustworthiness.
2. **Decentralization:** Blockchain operates on a decentralized network of computers, eliminating the need for a central authority or intermediary to validate transactions. This decentralized nature enhances transparency and reduces the risk of single points of failure or manipulation.
3. **Smart Contracts:** Smart contracts are self-executing contracts with predefined terms and conditions written in code. In the context of shipment tracking, smart contracts can automate various processes, such as verifying delivery milestones, triggering payments, and updating tracking information in real time.
4. **Transparency and Traceability:** Transactions recorded on the blockchain are transparent and auditable, providing stakeholders with a comprehensive view of the entire supply chain. By scanning QR codes or RFID tags attached to containers, stakeholders can track the movement of goods in real-time, enhancing visibility and traceability.
5. **Enhanced Trust:** Blockchain's immutability and transparency foster trust among stakeholders by providing a tamper-proof record of all transactions. Parties can verify the authenticity of tracking information and ensure compliance with contractual agreements, reducing the risk of disputes and misunderstandings.

4.1.4 Benefits of Blockchain in Shipment Tracking:

- **Real-Time Visibility:** Blockchain enables real-time tracking of shipments, allowing stakeholders to monitor cargo movements and status updates throughout the supply chain.
- **Streamlined Processes:** Automation through smart contracts streamlines shipment tracking processes, reducing manual interventions, paperwork, and processing times.
- **Improved Efficiency:** By eliminating data silos and enhancing transparency, blockchain improves operational efficiency, resource utilization, and decision-making across the supply chain.

- **Enhanced Security:** Blockchain's cryptographic algorithms and consensus mechanisms ensure the security and integrity of tracking data, reducing the risk of fraud, tampering, and unauthorized access.
- **Cost Savings:** Blockchain reduces administrative costs, disputes, and delays associated with traditional tracking processes, leading to cost savings for stakeholders.

Blockchain technology may be applied in the marine industry to trace shipments using a computer programme that would involve all relevant parties. A programme would authorise and proceed to the next stage of the transaction once documents were authorised and signed by parties. For instance, different types of data or documents might be uploaded to a blockchain, enabling parties to directly negotiate on the network without the involvement of third parties. In conclusion, the agreement would be automatically carried out by network consensus, and pertinent data would be posted for the benefit of all parties involved (Joseph, 2018). The blockchain could handle the storage and management of all pertinent cargo data in a "block," eliminating the need for middlemen to register, track, and authenticate data (Botton, 2018).

Blockchain technology has the potential to benefit all parties involved in tracking and tracing shipments.

a. carriers could benefit from decreased wait times and reloading times by exchanging information in real time, such as confirmation of ship arrival. They could also benefit from decreased loss, delays, and inefficiencies in the event that inaccurate information is communicated, as email is typically used for communications. Lastly, carriers could benefit from having a common location for information throughout the supply chain.
b. Ship Operators: offering a standardised interface, enabling real-time interchange of more comprehensive information on shipments, lowering expenses through online communication, and enabling purchasers to use the system to independently track occurrences in their system.
c. Intermediaries: provide a uniform space for gathering information from several sources; enabling better visibility and saving time when fixing errors in paperwork; creating a safe audit trail connecting original papers with customs declarations.
d. Terminals: by offering a common platform, they lower expenses and streamline communication between ports and shipping lines.

e. Insurance companies: guaranteeing data uniformity by providing the same version of critical data to all parties. Since data are always accessible, greater intelligence, risk assessment, and study of trends and hazards are all made possible.
f. Regulators: making faster, more comprehensive information available to enable better targeting and choices about which containers to inspect. Increasing automation and decreasing paperwork will free up regulator's attention for other important tasks.

4.2 Smart Contracts

4.2.1 Identifying problems associated with contractual procedures

Indian ports serve as critical nodes in the country's maritime infrastructure, facilitating the movement of goods and contributing significantly to trade and economic growth. The Indian container shipping industry thrives on intricate contractual agreements between various stakeholders - shipping lines, port authorities, customs departments, freight forwarders, and terminal operators. However, traditional contractual processes in these ports are often burdened with paperwork, delays, and disputes, leading to inefficiencies and increased transaction costs.

When compared to payments in other sectors, the current maritime payment procedure is somewhat inefficient in a number of areas. First, there is the absence dearth of automation, which is especially problematic for small and medium-sized shippers and forwarders as manual labour is involved in billing, and cheques and bank transfers are the usual ways that payments are made. Shippers need to put in between two and fifteen minutes of human labour processing each invoice, and much more if the invoices are inaccurate. Larger corporations typically employ long-term contracts and IT solutions for freight invoicing and payment, whereas smaller companies and organisations (shippers and forwarders) typically bear the expenses and repercussions of these inefficiencies (Drewry, 2018; Hellenic Shipping News, 2018).

Typical port contracts in India involve a complex chain of agreements, including:

- **Bills of Lading (B/L):** Negotiable documents issued by carriers acknowledging receipt of cargo and outlining transportation terms.

- **Terminal Handling Contracts (THCs):** Agreements between shipping lines and terminal operators defining fees and services for container handling within the port.
- **Customs Clearance Agreements:** Contracts outlining procedures for customs inspections and duty payments.
- **Freight Forwarding Agreements:** Contracts between shippers and freight forwarders outlining logistics management responsibilities.

These agreements involve extensive paperwork, manual verification, and potential delays:

- **Paperwork Overload:** Negotiating, signing, and exchanging paper-based contracts are time-consuming and prone to errors.
- **Verification Hurdles:** Manual verification of documents like B/Ls can lead to delays and discrepancies.
- **Dispute Resolution Friction:** Interpretation of contractual terms can lead to disputes, requiring time-consuming legal intervention.
- **Multiple Intermediaries:** Contractual processes in Indian ports involve various stakeholders, including shipping lines, freight forwarders, customs authorities, and port operators, leading to complexity and coordination challenges.

Contractual relationships within the container shipping industry are complex and multifaceted, involving operational, financial, and contractual aspects. The relationships between container terminals and liner shipping companies are particularly sophisticated, highlighting the importance of effective governance mechanisms in ensuring smooth operations[1] (Sağlam & Çetin, 2018). Moreover, the adoption of total quality management and supply chain integration practices has been shown to positively influence the firm performance of container shipping companies (Thai & Jie, 2018).

Challenges like disruptions in maritime transport networks and regulatory impacts on shipping operations underscore the necessity for more streamlined processes (Calatayud et al., 2017; Sheng et al., 2017). Blockchain technology and smart contracts present promising solutions to enhance the efficiency of the contractual process in container

[1] Sağlam, B. and Çetin, Ç. (2018). A qualitative examination of relational and contractual governance mechanisms in aliaga port cluster. Journal of Eta Maritime Science, 6(4), 365-378. https://doi.org/10.5505/jems.2018.16362

shipping. By ensuring secure, transparent, and automated contract execution, blockchain can reduce disputes, streamline documentation processes, and enhance trust among parties (Kim et al., 2023).

4.2.2 Role of Blockchain in Smart Contracts

Smart contracts, enabled by blockchain technology, offer automation capabilities that can streamline various aspects of the contractual process in container shipping. These contracts can automate tasks such as verifying conditions, executing agreements, monitoring container movements, triggering payments upon successful delivery, and enforcing terms and conditions in real-time[2] (Kamble et al., 2018; Guo et al., 2022; Harshvardhan & Teoh, 2022; Madhwal et al., 2022).

Blockchain technology ensures secure, transparent, and automated contract execution, reducing disputes, streamlining documentation processes, and enhancing trust among parties involved in container shipping contracts[3] (Elmay et al., 2022; Elmay et al., 2022). The decentralized and immutable nature of blockchain enhances the security and reliability of the contractual process, reducing the risk of fraud and manipulation. Smart contracts, self-executing contracts stored on a blockchain, offer a transformative solution for port contractual processes. Here's how:

- **Automated Execution:** Smart contracts encode terms and conditions within code, automatically triggering actions upon fulfillment of pre-defined criteria.

Example: A smart B/L could release cargo upon verification of payment by the importer, eliminating the need for manual document checks.

- **Enhanced Transparency and Security:** Stored on a blockchain, smart contracts offer a secure and transparent record of agreements, accessible to all authorized parties in real-time.
- **Reduced Disputes:** The immutability of the blockchain ensures that contract terms cannot be tampered with, minimizing room for disputes arising from misinterpretation.

Automating Specific Processes:

[2] Kamble, S., Gunasekaran, A., & Arha, H. (2018). Understanding the blockchain technology adoption in supply chains-indian context. International Journal of Production Research, 57(7), 2009-2033. https://doi.org/10.1080/00207543.2018.1518610

[3] Elmay, F., Salah, K., Jayaraman, R., & Omar, I. (2022). Using nfts and blockchain for traceability and auctioning of shipping containers and cargo in maritime industry. Ieee Access, 10, 124507-124522. https://doi.org/10.1109/access.2022.3225000

Here's a breakdown of how smart contracts can automate specific aspects of port contracts:

- **Bills of Lading:** Smart B/Ls can automate cargo release upon confirmation of payment received, expedite customs clearance, and eliminate the risk of fraud associated with paper B/Ls.
- **Terminal Handling Contracts:** Smart THCs can ensure automatic payment to terminal operators upon completion of agreed-upon services, streamlining cash flow.
- **Customs Clearance:** Smart contracts can integrate with customs systems, enabling automated document verification and faster cargo release.

Benefits of Smart Contracts in Indian Ports

Implementing smart contracts in Indian ports can bring in several benefits:

- **Reduced Paperwork:** Elimination of physical documents minimizes administrative burden and storage requirements.
- **Increased Efficiency:** Automating contract execution and verification reduces delays, leading to smoother cargo movement.
- **Enhanced Security:** Blockchain technology ensures secure and tamper-proof records of agreements, minimizing fraud risk.
- **Reduced Disputes:** Clear and transparent contracts with self-executing terms minimize potential disagreements.
- **Improved Visibility:** Real-time access to contract details for all authorized parties enhances transparency and accountability.

The integration of blockchain and smart contracts can facilitate collaboration between different entities in the container shipping industry, enabling seamless interactions, data sharing, and value circulation (Xue et al., 2023). This collaboration can lead to improved operational efficiency, reduced administrative burden, and enhanced trust among stakeholders.

Blockchain technology and smart contracts can address challenges related to data sharing, privacy, and security in the container shipping industry. By providing a decentralized and immutable ledger for recording transactions, blockchain technology ensures data integrity and transparency, while smart contracts enable secure and

automated data sharing among industrial entities . This not only streamlines operations but also encourages cooperation and value circulation within the industry.

The adoption of blockchain technology and smart contracts in the container shipping industry has the potential to optimize contractual processes, enhance efficiency, and drive innovation in maritime trade operations. Embracing these technologies can help the industry overcome challenges, improve transparency, and establish a more secure and efficient ecosystem for global trade.

4.3 Smart Bills of Lading

4.3.1 Identifying the problem

A bill of lading (B/L) is a crucial document in the shipping industry that serves as a contract of carriage between the shipper and the carrier. It functions as a receipt for the goods shipped, evidence of the contract of carriage, and a document of title to the goods. The B/L outlines the terms and conditions of the transportation agreement, including details of the cargo, the parties involved, the origin and destination of the shipment, and the agreed-upon freight charges[4] (Plomaritou & Voudouris, 2019)Pejović, 2020).

The procedures associated with a bill of lading involve several key steps. Initially, the shipper prepares the B/L, providing accurate information about the cargo being shipped. Once the goods are received for shipment, the carrier or their agent issues a received for shipment bill of lading. Subsequently, when the goods are loaded onto the vessel, a shipped bill of lading is issued. The B/L is then sent to the consignee, who can use it to claim the goods upon arrival at the destination port (Plomaritou & Voudouris, 2019).

The bill of lading plays a critical role in international trade by serving as a negotiable instrument that can be used for various purposes, including obtaining payment, transferring ownership of the goods, and accessing the cargo at the destination port. It is a key document that facilitates the smooth flow of goods through the supply chain and

[4] Plomaritou, E. and Voudouris, I. (2019). The relationships of bill of lading, charterparty and other transport documents. Journal of Economics Management and Trade, 1-8. https://doi.org/10.9734/jemt/2019/v24i630182

ensures that all parties involved in the transportation process are aware of their rights and responsibilities (Plomaritou & Voudouris, 2019; Pejović, 2020).

The current system of paper-based bills of lading in the maritime trade industry is facing challenges that hinder its efficiency and effectiveness. The traditional paper bill of lading system can lead to delays, inefficiencies, and risks associated with physical document handling. The reliance on paper documents for the transfer of goods can result in delays in the shipping process, especially when original copies need to be physically transported to different parties.

Manual processing of paper bills of lading can introduce errors, disputes, and increased administrative costs. The physical handling, verification, and storage of paper documents can add complexity to the shipping process and lead to inefficiencies in document management (Perkušić et al., 2020; Schmitz, 2011). Additionally, the paper-based system lacks transparency and real-time tracking capabilities, making it challenging to monitor the status and location of goods in transit (Shavaleev, 2024).

Moreover, the use of paper bills of lading limits the potential for technological advancements and digitalization in maritime trade. The industry's slow adoption of electronic bills of lading and blockchain-based solutions impedes progress towards more efficient and secure document management practices (Al-Azzam, 2022; Ratajczak, 2023).

The industry's reluctance to transition to electronic systems restricts its ability to leverage innovations that could streamline processes, reduce costs, and enhance transparency (Al-Azzam, 2022; Ratajczak, 2023). Recognizing these challenges, there is a growing acknowledgment of the necessity to modernize the bill of lading system in maritime trade. Embracing electronic bills of lading and blockchain technology has the potential to address the shortcomings of the current paper-based system by providing secure, transparent, and efficient digital solutions for document management (Al-Azzam, 2022; Ratajczak, 2023). Through digital transformation, the industry can overcome the limitations of the traditional bill of lading system and enhance the overall efficiency and reliability of maritime trade operations.

4.3.2 The Role of Blockchain for Bills of Lading

The implementation of blockchain technology for bills of lading in the maritime trade industry holds significant potential to revolutionize document management, enhance security, and streamline processes. A smart bill of lading, enabled by blockchain, offers a digital solution that can transform the traditional paper-based system into a secure, transparent, and efficient method of managing shipping documentation[5] Shi & Wang (2021)Baştuğ et al., 2020; Abdellatif, 2020).

Blockchain technology facilitates real-time tracking and transparency in the movement of goods through the supply chain. Smart bills of lading can be updated instantaneously as goods progress from origin to destination, providing stakeholders with visibility into the status and location of shipments (Shi & Wang, 2021; Baştuğ et al., 2020). This transparency not only improves operational efficiency but also enables proactive decision-making and risk management.

Blockchain technology provides a decentralized and tamper-proof platform for storing and managing bills of lading. By leveraging blockchain's distributed ledger technology, smart bills of lading can offer enhanced security, transparency, and traceability throughout the shipping process. Each transaction recorded on the blockchain is immutable, ensuring the integrity and authenticity of the document (Baştuğ et al., 2020; Abdellatif, 2020). Smart bills of lading can automate various processes, such as verification, transfer of ownership, and payment settlements, through the use of smart contracts. Smart contracts are self-executing contracts with predefined rules encoded into them. They enable automated execution of contractual terms, reducing the need for manual intervention and minimizing the risk of errors or disputes.

IBM and Maersk's TradeLens alliance makes use of a beta version of a blockchain-based system. It permits the processing of Sea Waybills and Bills of Lading, or "actionable doc flows." The TradeLens lists the following advantages of actionable document flows: easier transmission of shipping guidelines; control over document versions and statuses; expedited submission of shipping guidelines to the final Bill of Lading's development; document sharing with all parties with permission (fast); as well as the documents' auditability, traceability, and immutability. The shipper, carrier, and any other pertinent

[5] Baştuğ, S., Akan, E., & Battal, T. (2020). A conceptual system of blockchain-based electronic bill of lading., 454-469. https://doi.org/10.4018/978-1-7998-1397-2.ch024

parties with permission may use this system to If permitted by authorization, see the shipment, the transport apparatus, and the papers (TradeLens, 2020). TradeLens is a permissioned blockchain technology that operates privately.

To successfully implement blockchain-based smart bills of lading across Indian ports, several key considerations need to be addressed. Firstly, there is a need for collaboration among port authorities, shipping companies, and technology providers to establish common standards and protocols for blockchain integration (Zhou et al., 2020). Developing interoperable systems that can seamlessly exchange blockchain-based bill of lading data is essential for ensuring smooth operations across different ports and stakeholders. Additionally, regulatory frameworks and legal provisions must be updated to recognize and support the validity of electronic bills of lading stored on blockchain platforms (Ratajczak, 2023; Abdellatif, 2020). Clear guidelines on the legal status and enforceability of smart bills of lading will be crucial for fostering trust and adoption among industry participants. Training programs and awareness campaigns can also help educate stakeholders about the benefits and functionalities of blockchain technology in the context of bills of lading (Zhou et al., 2020; Ratajczak, 2023).

By embracing blockchain technology and smart bills of lading, Indian ports can enhance the efficiency, security, and transparency of their operations. The adoption of digital solutions in document management can lead to cost savings, reduced administrative burden, and improved overall performance in the maritime trade sector.

4.4 Fuel Quality Traceability and Assurance

4.4.1 Identifying the problem

Within the global trade landscape, the maritime industry occupies a position of critical importance, with containerized shipping functioning as the very foundation of this interconnected network. Despite its undeniable economic contributions, the industry grapples with persistent challenges, particularly in guaranteeing the traceability and quality assurance of fuels utilized by container vessels

Fuel quality traceability and assurance in maritime trade face several challenges that impact operational efficiency, environmental sustainability, and regulatory compliance. One of the primary issues is the lack of a robust traceability system for monitoring the quality and origin of fuels used in maritime vessels. The absence of transparent and standardized processes for tracking fuel sources and quality parameters can lead to

uncertainties regarding fuel composition, origin, and compliance with environmental regulations[6] (Langella et al., 2016).

Another significant problem is the potential for fuel contamination and adulteration, which can compromise engine performance, increase emissions of air pollutants, and pose risks to marine ecosystems. Without adequate traceability measures, it becomes challenging to identify and address instances of fuel quality deviations, leading to operational disruptions and environmental harm (Langella et al., 2016). The complexity of fuel supply chains in maritime trade contributes to traceability challenges. The multi-tiered nature of fuel sourcing, transportation, and bunkering operations creates opportunities for quality discrepancies and fraudulent practices along the supply chain. Inadequate monitoring and verification mechanisms exacerbate the risks associated with fuel quality assurance, posing threats to vessel safety, operational reliability, and environmental protection (Langella et al., 2016).

4.4.1.1 Current Problems in Fuel Quality Traceability and Assuranc:

- **Quality Variability:** The fuel used by container ships can exhibit significant variations in quality due to factors like geographic origin, refining processes employed, and storage conditions. This inconsistency makes it difficult to maintain uniform standards across different suppliers and locations.
- **Counterfeit Fuel Risk:** The presence of counterfeit or adulterated fuels in the market poses a serious threat to container shipping operators. These fuels can not only negatively impact engine performance but also introduce safety hazards and contribute to increased environmental pollution.
- **Lack of Traceability::** The intricate supply chain in the maritime industry often lacks robust mechanisms to trace fuel sourcing and distribution. This lack of transparency makes it challenging to track the origin and quality of fuel throughout the shipping process, hindering accountability and increasing the risk of non-compliance with regulations.

[6] Langella, G., Iodice, P., Amoresano, A., & Senatore, A. (2016). Ship engines and air pollutants: emission during fuel change-over and dispersion over coastal areas. International Journal of Energy and Environmental Engineering, 7(3), 307-320. https://doi.org/10.1007/s40095-016-0211-7

• **Regulatory Compliance:** Stringent environmental regulations, particularly those established by the IMO, mandate container shipping companies to adhere to strict fuel quality standards and emission limitations. However, ensuring compliance with these regulations remains a significant challenge due to the aforementioned issues related to fuel quality management.

Maritime pollution is a pressing issue driven by various factors, including fuel combustion emissions, ballast water discharge, and accidental oil spills. The combustion of marine fuels, particularly heavy fuel oil (HFO), releases pollutants such as sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter, and greenhouse gases (GHGs) into the atmosphere, contributing to air pollution and climate change (Langella et al., 2016).

In response to these challenges, the International Maritime Organization (IMO) has implemented regulations to combat maritime pollution and promote sustainable shipping practices. The IMO's MARPOL Annex VI sets limits on sulfur content in marine fuels, mandating the use of low-sulfur fuels or alternative compliance methods such as exhaust gas cleaning systems (scrubbers) to reduce SOx emissions (Langella et al., 2016).

Additionally, the IMO's Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) regulations aim to improve the energy efficiency of existing vessels and reduce carbon intensity in the maritime sector. These measures incentivize shipowners to adopt fuel-efficient technologies, optimize operational practices, and mitigate greenhouse gas emissions to meet international environmental standards (Langella et al., 2016).

4.4.2 The Role of Blockchain for Fuel Quality Traceability and Assurance

Blockchain technology offers a transformative solution for enhancing fuel quality traceability and assurance in maritime trade. By leveraging blockchain's decentralized and immutable ledger, the maritime industry can address key challenges related to fuel quality monitoring, verification, and compliance. The application of blockchain in fuel traceability can revolutionize the way fuel data is recorded, shared, and verified

throughout the supply chain, ensuring transparency, security, and efficiency in fuel management processes[7] (Yuthas & Appleyard, 2022; Ratajczak, 2023).

One of the primary roles of blockchain in fuel quality traceability is to establish a tamper-proof record of fuel transactions, from production and distribution to consumption. Each fuel batch can be assigned a unique digital fingerprint or token on the blockchain, enabling stakeholders to track its origin, composition, and quality parameters in real-time. This transparency enhances trust among parties and facilitates quick identification of any discrepancies or irregularities in fuel quality (Yuthas & Appleyard, 2022; Ratajczak, 2023).

Moreover, blockchain technology enables smart contracts, self-executing agreements coded on the blockchain, to automate compliance checks and quality assurance processes. Smart contracts can be programmed to trigger alerts or actions when predefined quality thresholds are not met, ensuring that only compliant fuels are used in maritime vessels. This automation streamlines verification procedures, reduces human error, and enhances the overall reliability of fuel quality assurance mechanisms[8](Papadakis & Kopanaki, 2022; Belu et al., 2021).

Blockchain-based fuel traceability systems can facilitate seamless data sharing and collaboration among industry stakeholders. By providing a secure and transparent platform for sharing fuel quality data, blockchain fosters interoperability and information exchange across the maritime supply chain. This enhanced visibility into fuel transactions and quality parameters enables proactive decision-making, risk management, and regulatory compliance in fuel management practices (Shen & Peña-Mora, 2018; Jain et al., 2014).

To successfully implement blockchain for fuel quality traceability and assurance in maritime trade, collaboration among industry players, regulators, and technology

[7] Yuthas, K. and Appleyard, M. (2022). The role of interdependencies in blockchain adoption: the case of maritime trade. The Journal of British Blockchain Association, 5(2), 1-11. https://doi.org/10.31585/jbba-5-2-(6)2022

[8] Papadakis, M. and Kopanaki, E. (2022). Innovative maritime operations management using blockchain technology & standardization. Journal of Ict Standardization. https://doi.org/10.13052/jicts2245-800x.1041

providers is essential. Establishing common standards, protocols, and interoperable systems for blockchain integration can promote widespread adoption and ensure the scalability of blockchain solutions across different ports and shipping companies. Additionally, investing in training programs and awareness campaigns can help educate stakeholders about the benefits and functionalities of blockchain technology in fuel quality management (Ahmad et al., 2022; Yik et al., 2021)

CHAPTER V

BLOCKCHAIN: CHALLENGES AND ROADMAPS TO SUCCESS

5.1 Blockchain Challenges in the Maritime Sector

Blockchain technology has emerged as a disruptive force with the potential to revolutionize various industries, including the maritime sector. In the context of maritime trade, blockchain offers a decentralized and transparent platform for secure data exchange, transaction verification, and supply chain management. While the adoption of blockchain in the maritime industry holds promise for enhancing operational efficiency, transparency, and security, it also presents unique challenges that need to be addressed to realize its full potential. As the maritime industry navigates the complexities of digital transformation and seeks innovative solutions to enhance efficiency and transparency, understanding the challenges and opportunities associated with blockchain adoption becomes paramount. In the subsequent sections of this report, we will delve deeper into the specific challenges, barriers, and implications of blockchain adoption in the maritime sector to provide a comprehensive analysis of the current state of blockchain technology in the maritime industry.

5.1.1 Shipping Industry Culture

The integration of blockchain technology in the maritime sector encounters challenges due to the prevailing culture within the shipping industry. A significant obstacle is the lack of comprehensive and integrated information, which hampers the adoption of blockchain in shipping operations[1] (Dutta et al., 2020). Furthermore, stakeholders and enterprises in the maritime transport sector face difficulties related to awareness, collaboration, and commitment, which are crucial for successful blockchain implementation (Jović et al., 2020). The absence of standardization in data elements

[1] Dutta, P., Choi, T., Somani, S., & Butala, R. (2020). Blockchain technology in supply chain operations: applications, challenges and research opportunities. Transportation Research Part E Logistics and Transportation Review, 142, 102067. https://doi.org/10.1016/j.tre.2020.102067

presents another hurdle, complicating the establishment of uniform practices across the industry (Munim et al., 2021).

To tackle these challenges effectively, it is essential to take into account policy implications and invest in talent acquisition and education concerning blockchain within the maritime industry (Zhou et al., 2020). Developing frameworks that improve transparency and process efficiency through blockchain implementation can result in substantial enhancements in the sector[2] (Abushaikha, 2023). Exploring the primary drivers and barriers of digital innovation, including blockchain applications, is vital to grasp the possibilities and limitations within the maritime industry (Gausdal et al., 2018).

In response to the COVID-19 pandemic, the maritime industry has been prompted to bolster its resilience through strategies like crew change management and capacity adjustments (Foo et al., 2022). Furthermore, the industry's shift towards decarbonization, as mandated by the International Maritime Organization, requires the adoption of technologies such as blockchain to support sustainability endeavors (Degiuli & Farkas, 2022). Embracing eco-design strategies and innovative propulsion technologies, like hydrogen-based systems, can further aid in reducing greenhouse gas emissions in maritime operations (Ansaloni et al., 2022).

Studies emphasize the importance of policy implications, talent acquisition, and education to accelerate blockchain implementation in the maritime industry (Zhou et al., 2020). Additionally, the readiness assessment framework highlights the difficulty of bringing different stakeholders together as a top challenge for blockchain adoption (Balasubramanian et al., 2021). The research also points out that blockchain technology supports solving many inefficiencies in global shipping operations but acknowledges the barriers that need to be overcome (Tan & Sundarakani, 2020).

While blockchain technology shows potential for transforming the maritime sector, its successful implementation is hindered by challenges arising from the industry's culture. Overcoming these obstacles demands a collective effort to address issues of information

[2] Abushaikha, I. (2023). Toward a model to enhance the applicability of blockchain in maritime shipping: a qualitative study from the middle east. Measuring Business Excellence, 28(1), 69-83. https://doi.org/10.1108/mbe-07-2023-0100

integration, standardization, awareness, and collaboration, alongside strategic policy interventions and investments in talent development and education.

5.1.2 Challenges Due to Privacy, Security, and Safety

The integration of blockchain technology in the maritime sector offers numerous benefits, including enhanced transparency, efficiency, and security. However, the implementation of blockchain in maritime operations also presents significant challenges related to privacy, security, and safety. Understanding and addressing these challenges is crucial to ensuring the successful adoption of blockchain in the maritime industry.

Privacy Concerns: One of the primary challenges in implementing blockchain in the maritime sector is ensuring data privacy and confidentiality. While blockchain offers transparency and immutability, the decentralized nature of the technology raises concerns about data privacy. The public nature of blockchain transactions can potentially expose sensitive information, compromising the privacy of stakeholders in the maritime supply chain. Ensuring data privacy while maintaining the benefits of blockchain transparency remains a critical challenge that needs to be addressed (Wang et al., 2020).

Security Risks: Security vulnerabilities pose another significant challenge in the implementation of blockchain in the maritime sector. Despite blockchain's reputation for being secure, the technology is not immune to cyber threats and attacks. Smart contracts, a key feature of blockchain, are susceptible to coding errors and vulnerabilities that can be exploited by malicious actors. The decentralized and distributed nature of blockchain makes it resistant to tampering, but individual nodes and smart contracts within the network can be susceptible to attacks. Ensuring the security of blockchain networks, data integrity, and protection against cyber threats is essential for the safe and reliable operation of blockchain systems in maritime trade (Wang et al., 2020).

Safety Considerations: Safety concerns also arise in the implementation of blockchain in the maritime sector, particularly in critical operations such as vessel management, cargo tracking, and port logistics. The reliance on blockchain for real-time data exchange and decision-making requires robust safety measures to prevent system failures, data breaches, and operational disruptions. Inaccurate or fraudulent information recorded on the blockchain can have serious implications for maritime operations, including vessel

navigation, cargo management, and regulatory compliance. Ensuring the safety and reliability of blockchain-enabled processes is essential to prevent accidents, mitigate risks, and maintain the integrity of maritime operations (Wang et al., 2020).

Interoperability Challenges: Interoperability, or the ability of different blockchain systems to communicate and exchange data seamlessly, is another challenge in the implementation of blockchain in the maritime sector. Integrating blockchain technology with existing maritime systems and processes poses technical and operational challenges. Legacy systems, interoperability issues, and scalability constraints can hinder the seamless adoption of blockchain solutions in maritime operations. The lack of standardized protocols, data formats, and interoperable systems hinders the integration of blockchain across diverse maritime platforms and stakeholders. Overcoming interoperability challenges is essential to ensure the efficient flow of information, data sharing, and collaboration in the maritime supply chain (Agbo et al., 2019; Haugum et al., 2022).

While blockchain technology offers transformative potential for the maritime sector, challenges related to privacy, security, and safety must be carefully addressed to ensure successful implementation. By developing robust privacy protection mechanisms, enhancing cybersecurity measures, prioritizing safety considerations, and promoting interoperability standards, the maritime industry can harness the benefits of blockchain technology while mitigating risks and ensuring the secure and efficient operation of blockchain-enabled systems.

5.1.3 Challenges due to Data Tampering

The challenges related to data tampering before uploading to the blockchain in the maritime sector are significant and can hinder the successful implementation of blockchain technology. Data manipulation is a serious concern in various industries, including maritime, as it can lead to inaccurate financial reporting, security breaches, and compromised trust[3] (Bergers et al. 2021). The integrity of data is crucial in ensuring the reliability and trustworthiness of information stored on the blockchain. Blockchain

[3] Bergers, J., Shi, Z., Korsmit, K., & Zhao, Z. (2021). Dwh-dim: a blockchain based decentralized integrity verification model for data warehouses.. https://doi.org/10.1109/blockchain53845.2021.00037

technology offers features such as tamper-proof data storage, immutability, and traceability, which are essential for maintaining data integrity (Zafar et al., 2022).

In the context of the maritime sector, ensuring the authenticity and accuracy of data before it is uploaded to the blockchain is paramount. The decentralized nature of blockchain technology, coupled with its cryptographic security features, helps prevent unauthorized tampering with data once it is recorded (Zhang et al., 2022). However, the challenge lies in ensuring that the data input into the blockchain is accurate and has not been tampered with prior to its entry.

Studies have highlighted the importance of data integrity in various sectors, including healthcare and finance, where the immutability and tamper-proof nature of blockchain technology play a crucial role in ensuring the security and reliability of data[4] (Neene et al., 2022; Zafar et al., 2022). Implementing mechanisms such as smart contracts and secure authentication schemes can further enhance data integrity and prevent tampering in maritime transportation systems [5](Mokhamed et al., 2023). To address the challenges of data tampering before uploading to the blockchain in the maritime sector, it is essential to implement robust data verification processes, secure authentication mechanisms, and encryption protocols to safeguard the integrity of data. Additionally, educating stakeholders about the importance of data integrity and implementing best practices for data management can help mitigate the risks associated with data tampering in blockchain implementation within the maritime industry.

5.1.4 Challenges due to Energy Consumption

The integration of blockchain technology in the maritime sector offers numerous benefits, including enhanced transparency, security, and efficiency. However, the

[4] Zafar, S., Hassan, S., Alsharef, M., Alahmadi, A., & Ullah, N. (2022). Implementation of a distributed framework for permissioned blockchain-based secure automotive supply chain management. Sensors, 22(19), 7367. https://doi.org/10.3390/s22197367

[5] Mokhamed, T., Talib, M., Moufti, M., Abbas, S., & Khan, F. (2023). The potential of blockchain technology in dental healthcare: a literature review. Sensors, 23(6), 3277. https://doi.org/10.3390/s23063277

adoption of blockchain in maritime operations is not without challenges, particularly concerning energy consumption. The energy-intensive nature of blockchain technology poses significant hurdles to its widespread implementation in the maritime industry. One of the primary challenges related to energy consumption in blockchain implementation is the computational power required for consensus mechanisms, such as proof-of-work (PoW) or proof-of-stake (PoS). These consensus algorithms demand substantial computational resources to validate transactions, secure the network, and maintain data integrity. As a result, blockchain networks consume significant amounts of energy, leading to environmental concerns and operational costs[6] (Dutta et al. 2020)(Nepal et al., 2022).

The scalability of blockchain systems in the maritime sector can be hindered by energy consumption challenges. As blockchain networks grow in size and complexity to accommodate a higher volume of transactions, the energy requirements for processing and validating data increase exponentially. This scalability issue poses a barrier to the efficient and sustainable deployment of blockchain solutions in maritime trade operations (Abushaikha, 2023; Serra et al., 2022). Another critical challenge is the environmental impact of blockchain energy consumption in the maritime sector. The carbon footprint associated with energy-intensive blockchain operations contributes to greenhouse gas emissions and environmental degradation. Given the maritime industry's focus on sustainability and emissions reduction, the high energy consumption of blockchain technology presents a significant obstacle to achieving environmental goals and regulatory compliance[7] (Zhou et al., 2020; Alladi et al., 2019). The cost implications of energy consumption in blockchain implementation can strain operational budgets and hinder the adoption of blockchain solutions in the maritime sector. The expenses associated with powering blockchain networks, maintaining hardware infrastructure, and managing energy-intensive processes can be prohibitive for maritime companies,

[6] Dutta, P., Choi, T., Somani, S., & Butala, R. (2020). Blockchain technology in supply chain operations: applications, challenges and research opportunities. Transportation Research Part E Logistics and Transportation Review, 142, 102067. https://doi.org/10.1016/j.tre.2020.102067

[7] Zhou, Y., Soh, Y., Loh, H., & Yuen, K. (2020). The key challenges and critical success factors of blockchain implementation: policy implications for singapore's maritime industry. Marine Policy, 122, 104265. https://doi.org/10.1016/j.marpol.2020.104265

especially for smaller operators with limited resources (Bürer et al., 2019; Jović et al., 2020). Addressing the challenges posed by energy consumption in blockchain implementation requires innovative solutions and strategic considerations. Efforts to optimize blockchain algorithms, transition to more energy-efficient consensus mechanisms, and explore alternative energy sources for blockchain operations can help mitigate the environmental impact and reduce energy consumption in the maritime sector. Collaboration among industry stakeholders, technology providers, and policymakers is essential to develop sustainable blockchain solutions that balance operational efficiency with environmental responsibility in maritime trade.

5.1.5 Challenges Due to Legal and Regulatory Concerns

Blockchain technology has gained significant attention for its potential to revolutionize various industries, including the container shipping sector in maritime trade. However, the implementation of blockchain in this industry is not without challenges, particularly those stemming from legal and regulatory concerns. Several studies shed light on the complexities associated with integrating blockchain technology into the container shipping industry and the implications of legal and regulatory frameworks on this process.

Legal and Regulatory Challenges in Blockchain Implementation: One of the key challenges identified in the literature is the need for regulatory frameworks to evolve in parallel with the development of blockchain applications [8](Balasubramanian et al., 2021). emphasize that for successful blockchain adoption, legal and regulatory frameworks must adapt to accommodate the unique features of blockchain technology (Balasubramanian et al., 2021). This highlights the necessity for regulatory bodies to keep pace with technological advancements to ensure compliance and mitigate risks associated with blockchain implementation in maritime trade.

Policy Implications for Blockchain Implementation: discuss critical success factors for blockchain implementation in Singapore's maritime industry, emphasizing the

[8] Balasubramanian, S., Shukla, V., Sethi, J., Islam, N., & Saloum, R. (2021). A readiness assessment framework for blockchain adoption: a healthcare case study. Technological Forecasting and Social Change, 165, 120536. https://doi.org/10.1016/j.techfore.2020.120536

importance of marine policy formulation in accelerating blockchain adoption (Zhou et al., 2020). The study underscores the significance of policies related to subsidies, investments, talent acquisition, and workforce training to facilitate the effective integration of blockchain technology in the maritime sector (Zhou et al., 2020). This suggests that regulatory policies play a pivotal role in shaping the landscape for blockchain implementation in container shipping.

Transparency and Process Efficiency Improvements: qualitative study highlights the positive outcomes of blockchain implementation in maritime shipping, particularly in terms of transparency and process efficiency enhancements[9] (Abushaikha, 2023). The findings suggest that blockchain technology can bring about improvements in transparency and operational efficiency within the maritime shipping industry, underscoring its potential to streamline processes and enhance visibility across the supply chain (Abushaikha, 2023).

Concerns in Developing Countries: focus on the challenges faced by developing countries, such as Montenegro, in adopting blockchain technology in maritime operations (Kapidani et al., 2021). The study underscores the specific concerns and obstacles encountered by developing nations in leveraging blockchain for container shipping, shedding light on the unique regulatory and infrastructural challenges that impede the widespread adoption of blockchain in maritime trade (Kapidani et al., 2021).

Money Laundering Considerations: Chuah 's work delves into the implications of money laundering in blockchain-based maritime trade and commerce, highlighting the importance of addressing regulatory gaps to mitigate risks associated with illicit activities (Chuah, 2022). The study underscores the need for robust regulatory mechanisms to combat money laundering and ensure compliance within blockchain-enabled maritime transactions, emphasizing the critical role of regulatory frameworks in safeguarding the integrity of container shipping operations (Chuah, 2022).

Zhou et al. (2020) stress the significance of marine policy development in tackling issues related to subsidies, investments, talent acquisition, and workforce training to expedite

[9] Abushaikha, I. (2023). Toward a model to enhance the applicability of blockchain in maritime shipping: a qualitative study from the middle east. Measuring Business Excellence, 28(1), 69-83. https://doi.org/10.1108/mbe-07-2023-0100

blockchain implementation in the maritime field. This underscores the necessity of a supportive regulatory framework to facilitate the effective incorporation of blockchain technology. Additionally, Balasubramanian et al. (2021) underscore the importance of regulatory and legal structures evolving in tandem with the advancement of new blockchain applications. They argue that adherence to regulations is vital for the successful uptake of blockchain technology. This aligns with the notion that regulatory frameworks should adapt to accommodate the distinct characteristics of blockchain to ensure its smooth integration into the container shipping industry. Strengthening regulatory supervision and enhancing compliance mechanisms are crucial to mitigate the risks associated with blockchain implementation in maritime trade.

In conclusion, the implementation of blockchain technology in the container shipping industry of maritime trade is confronted with various legal and regulatory challenges that necessitate a proactive approach to policy formulation, regulatory adaptation, and compliance mechanisms. Addressing these challenges effectively is essential to unlock the full potential of blockchain in enhancing transparency, efficiency, and security within maritime supply chains

5.1.6 Challenges due to Technology Integration and Interoperability

Blockchain technology has gained significant attention for its potential to revolutionize various industries, including the container shipping sector in maritime trade. The integration of blockchain in this industry offers benefits such as transparency, process efficiency improvements, traceability of shipping containers and cargo, and addressing longstanding inefficiencies (Abushaikha, 2023; Elmay et al., 2022; Harshvardhan & Teoh, 2022). However, the implementation of blockchain in the container shipping industry faces challenges related to technology integration and interoperability.

Challenges Due to Technology Integration: One of the primary challenges in implementing blockchain in the container shipping industry is the need for seamless technology integration. Blockchain technology requires integration with existing systems and processes, which can be complex and time-consuming. The compatibility of blockchain with legacy systems and the need for data migration pose significant challenges (Dutta et al., 2020; Zhou et al., 2020). Moreover, the lack of standardized

protocols for integrating blockchain with different systems hinders its smooth implementation (Kayıkçı & Subramanian, 2022).

Challenges Due to Interoperability: Interoperability is another critical challenge that affects the implementation of blockchain in the container shipping industry. Blockchain interoperability refers to the ability of different blockchain networks to communicate and share data effectively. In the context of maritime trade, where multiple stakeholders are involved in the shipping process, achieving interoperability among various blockchain platforms used by different entities becomes crucial [10](Kayıkçı & Subramanian, 2022). Lack of interoperability can lead to data silos, inefficiencies in information sharing, and hinder the seamless flow of data across the supply chain[11] (Dinesha & Balachandra, 2022).

Impact on Blockchain Implementation: The challenges of technology integration and interoperability in the container shipping industry have significant implications for the successful implementation of blockchain. Without addressing these challenges, the full potential of blockchain technology, such as enhancing transparency, improving process efficiency, and enabling traceability, may not be realized (Abushaikha, 2023; Elmay et al., 2022; Harshvardhan & Teoh, 2022). Overcoming these challenges is essential to unlock the benefits of blockchain in transforming the container shipping industry.

Recommendations for Addressing Challenges: To address the challenges of technology integration and interoperability in implementing blockchain in the container shipping industry, several strategies can be considered. Developing standardized protocols for integrating blockchain with existing systems, investing in workforce training and education on blockchain technology, and fostering collaboration among industry stakeholders to promote interoperability are crucial steps (Zhou et al., 2020; Kayıkçı & Subramanian, 2022). Additionally, policymakers can play a role in formulating marine

[10] Kayıkçı, Y. and Subramanian, N. (2022). Blockchain interoperability issues in supply chain: exploration of mass adoption procedures., 309-328. https://doi.org/10.1007/978-3-030-87304-2_13

[11] Dinesha, D. and Balachandra, P. (2022). Establishing interoperability in blockchain enabled interconnected smart microgrids using ignite cli.. https://doi.org/10.36227/techrxiv.21760700

policies that support blockchain implementation and incentivize investments in blockchain talent and knowledge acquisition (Zhou et al., 2020).

While blockchain technology holds great promise for enhancing the container shipping industry in maritime trade, challenges related to technology integration and interoperability must be carefully addressed. By overcoming these challenges through collaborative efforts, standardized protocols, and policy support, the container shipping industry can harness the full potential of blockchain to drive transparency, efficiency, and innovation in maritime trade.

5.1.7 Challenges due to Level of Competence and Knowledge

Blockchain technology has garnered significant attention for its potential to transform various industries, including the container shipping sector within the maritime industry. The implementation of blockchain in this sector presents numerous challenges, particularly concerning the level of competence and knowledge required for successful adoption. Several studies provide insights into the challenges faced and the impact of competence and knowledge on blockchain implementation in the container shipping industry.

One of the key challenges highlighted in the literature is the need for a deep understanding of blockchain technology and its applications in supply chain operations (Dutta et al., 2020; . Dutta et al., 2020) emphasize the importance of addressing challenges and exploring possibilities to enhance the maritime experience through blockchain technology. Similarly, Kamble et al. (2018) discuss the revolutionary paradigm shift that blockchain is expected to bring to supply chains, emphasizing the necessity for a comprehensive understanding of this technology for successful adoption.

Competence and knowledge gaps can hinder the effective implementation of blockchain in the container shipping industry. Abushaikha (2023) suggests that transparency and process efficiency improvements are outcomes of blockchain implementation, indicating the need for expertise to leverage these benefits effectively. Furthermore, Harshvardhan & Teoh (2022) stress the importance of understanding how blockchain can address inefficiencies in the shipping industry, underscoring the significance of competence in identifying and implementing solutions.

Zhou et al. (2020) highlight key challenges and critical success factors for blockchain implementation in the maritime industry, including the acquisition of blockchain talent and knowledge. This underscores the essential role of competence in driving successful blockchain adoption. Jović et al. (2020) also recognize the potential of blockchain technology in enhancing security and efficiency in container shipping operations, emphasizing the need for expertise to mitigate operational risks.

Moreover, the literature suggests that regulatory frameworks and legal aspects play a crucial role in blockchain implementation in the shipping industry. Perkušić et al. (2020) discuss the need for legal regulation of blockchain and smart contracts in the shipping sector, indicating the importance of legal knowledge and compliance in implementing blockchain solutions.

5.1.8 Challenges Due to Speed, Scalability, and Storage

One of the primary challenges faced in implementing blockchain in the container shipping industry is the issue of speed. Blockchain transactions can be time-consuming due to the consensus mechanisms involved in validating and adding transactions to the chain. This can lead to delays in processing transactions, which is a critical concern in the fast-paced environment of maritime trade. The need for real-time tracking and verification of shipments requires blockchain solutions to be optimized for speed to meet the industry's demands for timely and efficient operations (Abushaikha, 2023). Scalability Challenges: Scalability is another significant challenge that affects the implementation of blockchain in the container shipping industry. As the volume of transactions increases, traditional blockchain networks may struggle to handle the load efficiently, leading to bottlenecks and reduced performance. In the context of maritime trade, where a vast number of transactions occur daily across global supply chains, scalability issues can hinder the widespread adoption of blockchain technology. Addressing scalability challenges is crucial to ensure that blockchain networks can

support the growing demands of the container shipping industry while maintaining high performance levels [12](Rozman et al., 2022).

Storage Challenges: Storage requirements pose a unique challenge in implementing blockchain in the container shipping industry of maritime trade. The immutable nature of blockchain means that all transaction data is stored permanently on the chain, leading to a continuous increase in storage demands as the network grows. This can result in escalating costs associated with maintaining and managing large volumes of data, especially in a data-intensive industry like maritime trade. Finding efficient storage solutions that can accommodate the expanding data needs of blockchain networks is essential to overcome storage challenges and ensure the long-term viability of blockchain implementations in the container shipping sector (Tijan et al., 2019). While blockchain technology holds immense promise for transforming the container shipping industry in maritime trade, challenges related to speed, scalability, and storage must be effectively addressed to unlock its full potential. By developing innovative solutions to enhance transaction speed, improve scalability, and optimize storage capabilities, stakeholders in the maritime trade sector can overcome these challenges and leverage blockchain technology to drive efficiency, transparency, and security in container shipping operations.

5.1.9 Challenges due to System Costs

In the container shipping industry, the adoption of blockchain faces challenges primarily related to system costs. The integration of blockchain systems involves significant initial development costs and ongoing maintenance expenses (Zhou et al., 2020). These costs act as a barrier to the widespread implementation of blockchain technology in the maritime sector, where stakeholders traditionally rely on legacy systems (Bauk, 2022; Bauk, 2022).

One of the key challenges in the shipping industry is the lack of complete and integrated information, which hinders the seamless adoption of blockchain (Dutta et al., 2020).

[12] Rozman, N., Corn, M., Škulj, G., Diaci, J., & Podržaj, P. (2022). Scalability solutions in blockchain-supported manufacturing: a survey. Strojniški Vestnik – Journal of Mechanical Engineering, 68(10), 585-609. https://doi.org/10.5545/sv-jme.2022.355

Additionally, the maritime sector faces challenges related to inefficiencies and longstanding operational issues, which blockchain technology aims to address (Harshvardhan & Teoh, 2022). However, the high costs associated with blockchain implementation pose a significant obstacle to realizing these efficiency improvements.

Despite the potential benefits of blockchain in maritime shipping, such as enhancing port traffic management, container stacking, energy management, cost reduction, and improved security (Abushaikha, 2023), the financial implications of implementing blockchain solutions remain a concern. The cost factor is further compounded by the need for regulatory compliance, organizational restructuring, and educational efforts (Bauk, 2022).

Moreover, the maritime industry's hesitation to invest in blockchain systems is influenced by the industry's reliance on traditional processes and the perceived high costs of technological integration (Bauk, 2022). This reluctance to adopt blockchain technology is evident in the challenges faced by developing countries like Montenegro and South Africa in implementing blockchain solutions in the maritime sector (Kapidani et al., 2021).

To address these challenges, shipping companies may explore collaborative approaches, such as co-opetition, to develop new blockchain applications that benefit all industry competitors (Loh, 2024). By sharing the costs and resources required for blockchain implementation, companies can overcome financial barriers and drive innovation in the maritime sector.

While blockchain technology holds great promise for enhancing efficiency, security, and transparency in the container shipping industry of the maritime sector, the challenges posed by system costs must be carefully considered. Stakeholders need to collaborate, explore cost-sharing mechanisms, and develop strategies to mitigate the financial barriers associated with blockchain implementation to unlock the full potential of this transformative technology in maritime shipping.

5.2 Use of Blockchain in Maritime Applications: Recommendations for Maritime Sector Stakeholders

5.2.1 Build a Regulatory Framework

1. Policy Formulation: Collaborate with policymakers to develop regulations that support blockchain adoption in the maritime sector. Policies should address data privacy, security standards, smart contract legality, and interoperability with existing systems (Zhou et al., 2020).

2. Transparency and Efficiency: Emphasize the importance of transparency and process efficiency improvements as outcomes of blockchain implementation in maritime shipping (Abushaikha, 2023). Regulatory guidelines should focus on enhancing data visibility, reducing paperwork, and streamlining operations.

3. Regulatory Readiness Assessment: Implement a regulatory readiness assessment framework tailored to the maritime industry[13] (Sanda et al., 2022). This framework should evaluate the legal, technical, and operational readiness of stakeholders to leverage blockchain technology effectively.

4. Regulatory Compliance: Ensure that the regulatory framework aligns with international standards and best practices to facilitate cross-border transactions and global supply chain operations (Jović et al., 2020). Compliance with regulations will enhance trust among stakeholders and promote widespread blockchain adoption.

5. Smart Contracts and Certificates: Develop regulations for smart contracts and digital certificates to facilitate secure and legally binding transactions in the maritime sector[14] (Tyagi & Goyal, 2021). Establish protocols for issuing country of origin

[13] Sanda, O., Pavlidis, M., & Polatidis, N. (2022). A regulatory readiness assessment framework for blockchain adoption in healthcare. Digital, 2(1), 65-87. https://doi.org/10.3390/digital2010005

[14] Tyagi, N. and Goyal, M. (2021). Blockchain-based smart contract for issuance of country of origin certificate for indian customs exports clearance. Concurrency and Computation Practice and Experience, 35(16). https://doi.org/10.1002/cpe.6249

certificates, customs clearances, and other essential documents through blockchain-based smart contracts.

6. Regulatory Reforms: Stay abreast of regulatory reforms within the European Union and other jurisdictions related to blockchain solutions and smart contracts in the shipping industry (Perkušić et al., 2020). Engage with regulatory bodies to influence policy changes that support blockchain innovation while ensuring legal compliance.

7. Impact Assessment Framework: Implement a framework for assessing the impact of blockchain on midstream supply chain operations in the maritime industry (Lyridis et al., 2021). This framework should evaluate the benefits, challenges, and regulatory implications of deploying blockchain applications in specific maritime sectors.

8. Collaborative Initiatives: Foster collaboration among industry stakeholders, regulators, and technology providers to co-create regulatory standards for blockchain implementation[15] (Pu & Lam, 2020). Engaging in dialogue and knowledge-sharing can lead to the development of comprehensive regulatory guidelines that address the unique needs of the maritime sector.

5.2.2 Minimize Security and Safety Risks

1. Enhance Cybersecurity Measures: Implementing strong cybersecurity protocols, regular security assessments, and encryption techniques can safeguard blockchain networks from cyber threats (Pilkington, 2016).

2. Ensure Data Integrity: Establishing data validation mechanisms and real-time monitoring tools can help verify the accuracy and authenticity of information stored on the blockchain, reducing safety risks (Freire et al., 2022).

3. Collaborate with Industry Experts: Engaging with blockchain experts and cybersecurity professionals can provide valuable insights and guidance on best practices for secure blockchain implementation in the maritime sector (Pu & Lam, 2020).

[15] Pu, S. and Lam, J. (2020). Blockchain adoptions in the maritime industry: a conceptual framework. Maritime Policy & Management, 48(6), 777-794. https://doi.org/10.1080/03088839.2020.1825855

4. Invest in Employee Training: Educating maritime personnel on blockchain technology, cybersecurity best practices, and safety protocols can enhance awareness and readiness to address security and safety risks (Shava & Mhlanga, 2023).

5. Regular Risk Assessments: Conducting periodic risk assessments and audits can help identify potential vulnerabilities in blockchain systems and proactively address security and safety concerns (Freire et al., 2022).

5.2.3 Evaluate Energy Impacts

The energy impact associated with implementing blockchain systems is one critical aspect that maritime stakeholders must carefully evaluate. The integration of blockchain technology in the maritime sector has the potential to significantly impact energy consumption and sustainability efforts (Serra et al., 2022). Research indicates that blockchain technology can support the development of sustainable practices in the maritime industry by pursuing a "green" path to reduce energy consumption (Serra et al., 2022). By leveraging blockchain to streamline processes, enhance data integrity, and reduce the need for intermediaries, the maritime sector can potentially lower energy costs and contribute to environmental conservation efforts (Bauk, 2022).

Moreover, the energy sector itself has witnessed successful applications of blockchain technology, demonstrating increased economic and environmental efficiency in energy production processes (Karaszewski et al., 2021). By adopting blockchain solutions, the maritime sector can draw insights from the energy industry's experiences to optimize energy consumption and promote sustainability in maritime operations (Ullah et al., 2020).

To ensure the successful implementation of blockchain in the maritime sector while mitigating energy-related challenges, stakeholders should consider conducting a comprehensive evaluation of the energy impacts of blockchain integration. This evaluation should encompass factors such as energy consumption during blockchain transactions, the environmental footprint of blockchain systems, and the potential for energy savings through process optimization (Teng et al., 2021).

Furthermore, stakeholders in the maritime sector can benefit from exploring peer-to-peer (P2P) microgrid applications enabled by blockchain technology, which not only support renewable energy initiatives but also empower consumers and prosumers economically (Ahl et al., 2019). By leveraging blockchain for energy management and distribution, the maritime industry can enhance its sustainability practices and contribute to the global transition towards efficient energy use (Khatoon et al., 2019).

5.2.4 Educate and Build Capacity

1. Policy Implications and Talent: Acquisition Research suggests that policy formulation plays a crucial role in accelerating blockchain implementation in the maritime industry (Zhou et al., 2020). Policymakers should focus on providing subsidies and investments to support blockchain initiatives. Moreover, acquiring blockchain talent and knowledge through workforce training and education is essential for successful implementation (Zhou et al., 2020).

2. Transparency and Process Efficiency: Studies indicate that implementing blockchain in maritime shipping leads to improvements in transparency and process efficiency (Abushaikha, 2023). Stakeholders should be educated on how blockchain can streamline operations, reduce paperwork, and enhance trust among participants. Building capacity to understand these benefits is vital for successful adoption.

3. Reduction of Transaction: Costs Blockchain technology has the potential to reduce transaction costs in the maritime sector by eliminating intermediaries and enhancing financial efficiency (Bauk, 2022; Bauk, 2022). Educating stakeholders on the cost-saving benefits of blockchain and building their capacity to leverage this technology can drive its successful implementation.

4. Collaboration and Awareness: One of the critical challenges identified in the maritime transport sector is the lack of awareness, collaboration, and commitment among stakeholders for successful blockchain implementation[16] (Jović et al., 2020). Capacity-

[16] Jović, M., Tijan, E., Žgaljić, D., & Aksentijević, S. (2020). Improving maritime transport sustainability using blockchain-based information exchange. Sustainability, 12(21), 8866. https://doi.org/10.3390/su12218866

building initiatives should focus on fostering collaboration, raising awareness about blockchain benefits, and promoting a culture of innovation and cooperation.

5. Standards and Data Integrity: Ensuring data integrity and adherence to standards are essential for successful blockchain implementation in maritime operations (Papadakis & Kopanaki, 2022; Freire et al., 2022). Stakeholders should be educated on the strategic impact of standards and blockchain technology in enhancing operational processes and maintaining data reliability.

6. Building Trust and Capacity: Educating maritime stakeholders on the trust-building capabilities of blockchain technology is crucial for its successful implementation (Ramos & Queiroz, 2022). Capacity-building efforts should focus on fostering trust through secure and transparent data sharing, thereby creating a cooperative work environment conducive to blockchain adoption.

5.2.5 Developing Standards

1. Addressing Information Integration Challenges: Standards should prioritize tackling the issue of incomplete and fragmented information in the shipping industry (Dutta et al., 2020). By setting up protocols for data integration and sharing among stakeholders, standards can ensure that blockchain systems facilitate seamless information flow and enhance transparency in maritime operations.

2. Enhancing Transparency and Efficiency: Standards should strive to boost transparency and operational efficiency in maritime shipping through blockchain implementation (Abushaikha, 2023). By outlining guidelines for data visibility, authentication mechanisms, and smart contract usage, standards can foster trust among stakeholders and streamline operational processes in the maritime sector.

3. Considering Policy Formulation and Talent Acquisition: Standards should take into account policy implications, talent acquisition, and workforce training to expedite blockchain implementation in the maritime industry (Zhou et al., 2020). By delineating best practices for regulatory compliance, skill development, and knowledge transfer, standards can assist stakeholders in navigating the complexities of blockchain adoption and maximizing its advantages.

4. Promoting Collaboration and Commitment: Standards should underscore the significance of collaboration, awareness, and commitment among maritime enterprises for successful blockchain implementation (Jović et al., 2020). By promoting industry-wide cooperation, standards can cultivate a culture of innovation, knowledge sharing, and mutual support to surmount implementation challenges and propel sustainable blockchain adoption.

5. Emphasizing Standardization and Traceability: Standards should concentrate on standardization and traceability aspects of blockchain technology in maritime operations (Papadakis & Kopanaki, 2022). By defining common frameworks, data formats, and interoperability protocols, standards can ensure consistency, compatibility, and traceability of information exchanged through blockchain systems in the maritime sector.

6. Focusing on Cost Reduction and Energy Efficiency: Standards should aim to lower transaction costs and energy consumption in maritime operations through blockchain integration (Bauk, 2022). By advocating for cost-effective solutions, resource optimization, and energy-efficient practices, standards can help stakeholders overcome financial barriers and environmental impacts associated with blockchain implementation.

5.2.6 Assess Costs

To successfully implement blockchain in the maritime industry, stakeholders need to carefully assess the costs involved and develop strategies to mitigate financial barriers. Understanding the key challenges and critical success factors of blockchain implementation is crucial for devising cost-effective solutions (Zhou et al., 2020). Additionally, exploring the application prospects of blockchain technology in building interport communities can provide insights into the potential cost savings and operational efficiencies that blockchain can offer [17](Serra et al., 2022).

Recommendations for maritime stakeholders looking to implement blockchain technology include conducting a thorough cost-benefit analysis to evaluate the financial implications of adoption (Abushaikha, 2023). By identifying transparency and process

[17] Serra, P., Fancello, G., Tonelli, R., & Marchesi, L. (2022). Application prospects of blockchain technology to support the development of interport communities. Computers, 11(5), 60. https://doi.org/10.3390/computers11050060

efficiency improvements as outcomes of blockchain implementation, stakeholders can justify the costs associated with transitioning to blockchain-based systems (Abushaikha, 2023). Moreover, leveraging blockchain technology to reduce transaction costs, enhance data integrity, and improve information exchange can lead to long-term cost savings and operational benefits (Jović et al., 2020).

Maritime stakeholders need to collaborate and share best practices for blockchain implementation to optimize costs and maximize the benefits of this transformative technology (Pu & Lam, 2020). By considering the potential cost savings, efficiency gains, and sustainability improvements that blockchain can bring to the maritime sector, stakeholders can make informed decisions about investing in blockchain solutions (Jović et al., 2020). Despite the initial investment required, the long-term advantages of blockchain technology in terms of cost reduction and operational optimization make it a worthwhile consideration for maritime industry players (Bauk, 2022).

5.2.7 Evaluate Regulatory Compliance

Regulatory compliance is paramount for the successful implementation of blockchain technology. Numerous studies have underscored the primary challenges and critical success factors associated with blockchain implementation in the maritime sector (Zhou et al., 2020). These factors encompass policy implications, talent acquisition, and workforce training to expedite the adoption of blockchain technology.

A pivotal component of regulatory compliance involves fostering collaboration among stakeholders and enterprises within the maritime transport sector (Jović et al., 2020). Challenges such as lack of awareness, collaboration, and commitment have been identified as impediments to the effective implementation of blockchain technology. Hence, maritime stakeholders must collaborate in addressing these issues and ensuring regulatory compliance throughout the implementation phase.

Frameworks for regulatory readiness assessment can aid in evaluating the readiness of businesses and solution providers for blockchain adoption (Sanda et al., 2022). These frameworks evaluate the regulatory landscape to safeguard stakeholders' interests and facilitate the seamless integration of blockchain technology in the maritime sector. Additionally, early collaboration between the government and private sector on

regulatory compliance can set the stage for blockchain adoption across various industries, including maritime[18] (Alammary et al., 2019).

Adherence to existing regulatory frameworks, such as **GDPR**, is vital for the practical viability of blockchain applications (Hasselgren et al., 2020). Overcoming regulatory challenges, such as nascent applications and exploratory phases, is crucial for navigating the intricacies of blockchain initiatives in the maritime industry[19] (Osmani et al., 2020). By ensuring alignment with prevailing regulations and standards, maritime stakeholders can mitigate risks and capitalize on the emerging opportunities presented by blockchain technology (Pu & Lam, 2020).

[18] Alammary, A., Alhazmi, S., Almasri, M., & Gillani, S. (2019). Blockchain-based applications in education: a systematic review. Applied Sciences, 9(12), 2400. https://doi.org/10.3390/app9122400

[19] Osmani, M., El-Haddadeh, R., Hindi, N., Janssen, M., & Weerakkody, V. (2020). Blockchain for next-generation services in banking and finance: cost, benefit, risk and opportunity analysis. Journal of Enterprise Information Management, 34(3), 884-899. https://doi.org/10.1108/jeim-02-2020-0044

CHAPTER VI

SUMMARY AND CONCLUSION

The container shipping industry has been an integral part of global trade, enabling the movement of goods between countries and continents with remarkable speed and reliability. However, traditional processes in this industry have often been plagued by inefficiencies, lack of transparency, and security concerns. The introduction of Blockchain technology has brought about a paradigm shift in how container shipping operates. With the advancement of technology, especially Blockchain and smart contracts, the container shipping industry is undergoing a significant transformation. This report delves into the transformative impact of blockchain technology and smart contracts on the container shipping industry. Beginning with an overview of the current challenges faced by the industry, including inefficiencies in documentation, transparency issues, and delays in transaction settlements, the report systematically explores how blockchain and smart contracts offer innovative solutions to address these pain points.

Blockchain is a distributed ledger technology that enables secure and transparent record-keeping of transactions across multiple parties in a decentralized manner. Each transaction or data entry is stored in a block that is linked to previous blocks in chronological order, creating an immutable chain of information. This ensures data integrity, security against tampering or fraud, and real-time visibility for all stakeholders involved in the supply chain.

One key feature of Blockchain technology is its ability to establish trust among participants without relying on intermediaries or centralized authorities. By using consensus mechanisms such as proof-of-work or proof-of-stake, Blockchain networks validate transactions securely while maintaining anonymity for users. In addition to trust-building capabilities, Blockchain offers benefits like enhanced traceability, reduced costs through process automation, improved efficiency with real-time monitoring capabilities, and increased data security through encryption techniques.

The report provides a detailed explanation of blockchain technology, elucidating its decentralized and immutable nature, and its potential to revolutionize supply chain management. It delves into the concept of smart contracts, highlighting their ability to automate and streamline contractual agreements, thereby enhancing efficiency and reducing costs. Drawing on relevant literature and case studies, the report examines the practical applications of blockchain and smart contracts in container shipping, including provenance tracking, real-time visibility, and automated payment settlements.

Smart contracts are self-executing digital contracts coded with predefined rules and conditions that automatically enforce terms when specified criteria are met. In container shipping, smart contracts streamline various processes such as booking cargo space on vessels, tracking shipments in real-time using IoT devices embedded with sensors recording temperature/humidity levels inside containers - ensuring compliance with regulations while optimizing logistics operations seamlessly from end-to-end.

The implementation of smart contracts brings numerous advantages to container shipping operations including increased operational efficiency by automating manual tasks traditionally prone to errors or delays; enhanced transparency through audit trails showing every step taken during the shipment lifecycle; heightened security features protecting sensitive data from unauthorized access; accelerated dispute resolution mechanisms reducing time/costs associated with claims management processes.

The report critically evaluates the challenges and limitations associated with implementing blockchain and smart contracts in the container shipping industry. These challenges range from regulatory hurdles and interoperability issues to concerns regarding data privacy and security. By analyzing these challenges in-depth, the report offers insights into potential strategies and best practices for overcoming them, thereby enabling the successful adoption and integration of blockchain and smart contracts within the industry.

REFERENCES

Alammary, A., Alhazmi, S., Almasri, M., & Gillani, S. (2019). Blockchain-based applications in education: a systematic review. Applied Sciences, 9(12), 2400. https://doi.org/10.3390/app9122400

Zhang, W. (2022). The current situation and trend of blockchain technology in the financial field. Mobile Information Systems, 2022, 1-13. https://doi.org/10.1155/2022/7908625

Chen, G., Xu, B., Lu, M., & Chen, N. (2018). Exploring blockchain technology and its potential applications for education. Smart Learning Environments, 5(1). https://doi.org/10.1186/s40561-017-0050-x

Younas, A. and Wahaibi, M. (2023). Exploration of blockchain technology in the education sector in the sultanate of oman. International Journal of Academic Research in Business and Social Sciences, 13(4). https://doi.org/10.6007/ijarbss/v13-i4/15889

Tagliafico, A., Campi, C., Bignotti, B., Bortolotto, C., Buccicardi, D., Coppola, F., … & Faggioni, L. (2022). Blockchain in radiology research and clinical practice: current trends and future directions. La Radiologia Medica, 127(4), 391-397. https://doi.org/10.1007/s11547-022-01460-

Dubovitskaya, A., Baig, F., Xu, Z., Shukla, R., Zambani, P., Swaminathan, A., … & Wang, F. (2020). Action-ehr: patient-centric blockchain-based electronic health record data management for cancer care. Journal of Medical Internet Research, 22(8), e13598. https://doi.org/10.2196/13598

Dietrich, F., Louw, L., & Palm, D. (2023). Blockchain-based traceability architecture for mapping object-related supply chain events. Sensors, 23(3), 1410. https://doi.org/10.3390/s23031410

Kaur, H., Jameel, R., Alam, M., Alankar, B., & Chang, V. (2023). Securing and managing healthcare data generated by intelligent blockchain systems on cloud networks through dna cryptography. Journal of Enterprise Information Management, 36(4), 861-878. https://doi.org/10.1108/jeim-02-2021-0084

LI, X. (2022). A blockchain-based verifiable user data access control policy for secured cloud data storage. Computational Intelligence and Neuroscience, 2022, 1-12. https://doi.org/10.1155/2022/2254411

Ko, T., Lee, J., & Ryu, D. (2018). Blockchain technology and manufacturing industry: real-time transparency and cost savings. Sustainability, 10(11), 4274. https://doi.org/10.3390/su10114274

Sağlam, B. and Çetin, Ç. (2018). A qualitative examination of relational and contractual governance mechanisms in aliaga port cluster. Journal of Eta Maritime Science, 6(4), 365-378. https://doi.org/10.5505/jems.2018.16362

Kamble, S., Gunasekaran, A., & Arha, H. (2018). Understanding the blockchain technology adoption in supply chains-indian context. International Journal of Production Research, 57(7), 2009-2033. https://doi.org/10.1080/00207543.2018.1518610

Elmay, F., Salah, K., Jayaraman, R., & Omar, I. (2022). Using nfts and blockchain for traceability and auctioning of shipping containers and cargo in maritime industry. Ieee Access, 10, 124507-124522. https://doi.org/10.1109/access.2022.3225000

Alammary, A., Alhazmi, S., Almasri, M., & Gillani, S. (2019). Blockchain-based applications in education: a systematic review. Applied Sciences, 9(12), 2400. https://doi.org/10.3390/app9122400

Osmani, M., El-Haddadeh, R., Hindi, N., Janssen, M., & Weerakkody, V. (2020). Blockchain for next-generation services in banking and finance: cost, benefit, risk and opportunity analysis. Journal of Enterprise Information Management, 34(3), 884-899. https://doi.org/10.1108/jeim-02-2020-0044

Serra, P., Fancello, G., Tonelli, R., & Marchesi, L. (2022). Application prospects of blockchain technology to support the development of interport communities. Computers, 11(5), 60. https://doi.org/10.3390/computers11050060

Jović, M., Tijan, E., Žgaljić, D., & Aksentijević, S. (2020). Improving maritime transport sustainability using blockchain-based information exchange. Sustainability, 12(21), 8866. https://doi.org/10.3390/su12218866

Sanda, O., Pavlidis, M., & Polatidis, N. (2022). A regulatory readiness assessment framework for blockchain adoption in healthcare. Digital, 2(1), 65-87. https://doi.org/10.3390/digital2010005

Tyagi, N. and Goyal, M. (2021). Blockchain-based smart contract for issuance of country of origin certificate for indian customs exports clearance. Concurrency and Computation Practice and Experience, 35(16). https://doi.org/10.1002/cpe.6249

Kayıkçı, Y. and Subramanian, N. (2022). Blockchain interoperability issues in supply chain: exploration of mass adoption procedures., 309-328. https://doi.org/10.1007/978-3-030-87304-2_13

Dinesha, D. and Balachandra, P. (2022). Establishing interoperability in blockchain enabled interconnected smart microgrids using ignite cli.. https://doi.org/10.36227/techrxiv.21760700