ERASMUS UNIVERSITY ROTTERDAM

MSc Maritime Economics and Logistics

The academic year 2021-2022

"The Challenges of Blockchain Implementation in Ports"

by

Dimosthenis Papanastasiou

Student number: 612809

Supervisor:

Dr. Elvira Haezendonck

Abstract

The idea of changing the marine industry into a more digital and automated environment capable of real-time communication has quickly emerged as a topic of discussion within the industry. A significant portion of the discussion centered on Blockchain technology, which, due to its decentralization feature, has the potential to reduce the complexity of the network that constitutes the supply chain and to interconnect its participants. However, there have only been a few studies that have looked into the viability of it, and those studies haven't explored any restrictions other than the ones that are typically discussed.

The study aims to discover and summarize the problems associated with implementing Blockchain technology within the maritime industry, especially ports. According to the research, the technology has the potential to increase efficiency and profitability, but its expensive price and technical constraints prevent its broad adoption. In addition, the essay highlights limited decentralization, scalability, immutability, performance, cybersecurity, and privacy problems.

The paper concludes by examining several case studies of ports that have implemented Blockchain technology in their daily operations. The case studies show that by efficiently implementing Blockchain chain technology, the industry will have a number of benefits in its everyday operations and has also developed solutions to deal with the challenges of Blockchain technology.

Acknowledgments

My academic career concludes with the submission of this thesis. I made the decision to follow my aspirations and relocate to a different country about two years ago. At long last, I decided to pursue a Master's degree in Maritime Economics and Logistics at Erasmus University Rotterdam. My time as a student comes to an end with the submission of this paper.

I would like to take advantage of this chance to show my appreciation to everyone who was involved in ensuring that I was able to achieve this goal successfully.

To begin, I would like to express my gratitude to all of the instructors at Erasmus University Rotterdam for the time and effort they put into communicating their expertise to me. I would like to express my sincere appreciation to my supervisor, Dr. Elvira Haezendonck, for all of her support and assistance when supervising my job.

Moreover, I'd like to express my gratitude to my family for always being there to cheer me on and supporting every step I've taken toward achieving my educational goals, as well as for respecting my decision to leave my country and pursue my studies abroad.

Thank you for making it possible for me to complete my studies.

Table of Contents

ABSTRACT **2**

ACKNOWLEDGMENTS **3**

TABLE OF CONTENTS **4**

LIST OF ABBREVIATIONS **6**

LIST OF FIGURES **7**

1.INTRODUCTION **8**

1.1 WHAT IS BLOCKCHAIN? 8
1.2 THE FOUR TYPES OF BLOCKCHAIN. 9
1.3 PROOF OF WORK. 11
1.4 PROOF OF STAKE. 11
1.5 THE IMPORTANCE OF BLOCKCHAIN IN THE BUSINESS ENVIRONMENT. 12
1.6 PROBLEM STATEMENT. 13
1.7 MOTIVATION. 14
1.8 OVERVIEW OF THE PAPER. 15

METHODOLOGY. **15**

CHAPTER 2. ..... **16**

2.1 OVERVIEW OF BLOCKCHAIN APPLICATIONS IN THE MARITIME SHIPPING INDUSTRY. 16
2.2 BLOCKCHAIN DEVELOPMENTS IN THE SHIPPING INDUSTRY. 17
2.2.1 Electronic B/L using Blockchain Technology. *17*
2.3 OVERVIEW OF BLOCKCHAIN APPLICATIONS IN PORTS. 18
2.3.1 Global Navigation Satellite Systems. *18*
2.3.2 Quay Connect from the Port of Rotterdam. *19*
2.3.3 Secure Data Sharing Program. *19*
2.3.4 T-Mining. *20*
2.3.5 TradeLens. *20*
2.3.6 PortXchange. *21*
2.3.7 DAKOSY. *22*

CHAPTER 3. ..... **22**

3.1 JURISDICTIONAL AND GOVERNING LAW ISSUES. 23
3.2 FORCE MAJEURE. 24
3.3 LAND REGISTRY. 24
3.4 PRIVACY OF DATA. 25
3.5 LIMITATIONS OF SMART CONTRACTS. 26
3.6 INTELLECTUAL PROPERTY CHALLENGES IN SMART CONTRACTS. 27
3.7 COMPLIANCE WITH FINANCIAL AND TAX LAWS AND REGULATIONS. 29
3.7.1 AML/CFT. *30*
3.7.2 Complicated for collecting taxes. *30*
3.8 DUE DILIGENCE REQUIREMENTS. 30
3.9 ANTITRUST CONSIDERATIONS. 31
4.1 DIFFICULTIES IN ADAPTABILITY. 33
4.2 LIMITED DECENTRALIZATION. 33
4.3 SCALABILITY. 33
4.4 PERFORMANCE ISSUES. 34
4.5 CYBERSECURITY. 34
4.5.1 The 51% Attack. *34*
4.5.2 Unconfirmed Transaction Attack. *35*

4.5.3 Sybil/Eclipse Attack. *35*
4.5.4 DDoS Attack. *35*
4.5.5 Double-Spending. *36*
4.5.6 Attacks on Smart Contracts. *36*
4.6 Confidentiality. 37
4.7 Immutability issues. 37
4.8 High Development and Operational Costs. 38
4.9 Maturity issues. 39
4.10 Irreversible transactions. 40

CHAPTER 5. ..... **40**

5.1 Increasing efficiency. 41
5.2 Tracing the quality of fuel. 41
5.3 Blockchain's side effects on Sustainability in the maritime industry. 42

CHAPTER 6. ..... **43**

6.1 The Port of Thessaloniki. 43
6.2 Port of Hamburg. 45
6.3 Rotterdam Port and Response to Security and DDO Attacks. 47
6.4 Port of Valencia. 48
6.5 Cost Reduction in Block-Chain Technology. 48
6.6 Trust and Safety Concerns. 49
6.7 Wismar Seaport Case Studies. 50
6.8 Port of Antwerp Case Study. 53
6.9 The Port of Singapore. 53
6.10 The Hainan Free Trade Port- Case Study. 55

LIMITATIONS. **56**

CHAPTER 7. ..... **56**

7.1 Smart Contract. 61
7.2 Security Features. 62
7.3 Legal Issues in Blockchain Technology. 65
7.4 Environmental Concerns. 65
7.5 Energy Consumption. 66
7.6 Adaptability in Blockchain Technology in Maritime Ports. 66
7.7 Suggestion for further research. 67

REFERENCES. **69**

List of Abbreviations

AML/CFT	Anti-Money Laundering/Combating the Financing of Terrorism
B/L	Bill of Lading
DeFi	Decentralized Finance
GDPR	General Data Protection Regulation
EEDI	Energy Efficiency Design Index
IMO	International Maritime Organization
IOT	Internet of Things
IRS	Internal Revenue Service
PoS.	Proof of Stake
PoW	Proof of Work
SDG	Sustainable Development Goals

List of Figures

FIGURE 1: *: THE 4 MAIN TYPES OF BLOCKCHAIN TECHNOLOGY* 11

FIGURE 2: PROOF OF WORK VS. PROOF OF STAKE 12

FIGURE 3: THE LIFE CYCLE OF A SMART CONTRACT: PHASES, ACTORS, AND SERVICES. (SILLABER AND WALTL, 2017). 28

FIGURE 4 : COST OF BLOCKCHAIN IMPLEMENTATION: PROCESS (TAKYAR, N.D) 39

FIGURE 5: "BITCOIN AVERAGE ENERGY CONSUMPTION PER TRANSACTION COMPARED TO THAT OF VISA AS OF APRIL 25, 2022" (DE BEST, 2022). 43

1.Introduction

Blockchain is a cutting-edge technology that has the potential to completely alter how transactions are carried out. The invention of the well-known cryptocurrency Bitcoin signaled the beginning of the Blockchain revolution in the financial industry. These days, it is used in many different sectors to manage various data transactions, including ports. The complexity of port activities is currently causing a number of issues, like lack of yard capacity, overbooking of terminals, slow productivity, cargo tracking, and more. Blockchain is a cutting-edge technology already implemented in various ports around the globe to tackle these challenges. Mainly because of its transparency and decentralization, it can provide several benefits in terms of network trustworthiness and operational efficiency. However, experts are still mindful of the implementation of Blockchain in ports, as several challenges have been identified, which will be discussed later in the paper.

1.1 What is Blockchain?

Blockchain technology, also known as Distributed Ledger Technology (DLT), was initiated in 1991. Still, it was first introduced in 2008 in the form of a cryptocurrency (Bitcoin) and is defined as “a distributed database or ledger that is shared among the nodes of a computer network.” According to the definition, a Blockchain is an electronic database; however, its functions differ from the traditional ones. The primary purpose of this technology is to store information in a digital form. This information is collected in groups, also known as “blocks.” These blocks have specific storage limits, and when they are filled, they close and link to the last filled block, framing a chain of data and information known as the Blockchain. Moreover, the main goal of Blockchain is to let digital data to be distributed and documented but not modified. Therefore, the records of transactions in a Blockchain cannot be deleted, destroyed, or changed (Hayes, 2022). Blockchain was first known for its applications in decentralized finance (DeFi) and in cryptocurrencies. However, nowadays, blockchain is also used as a management solution tool in every industry around the globe, including banking and finance, ports, and supply chains. As Blockchain continues to evolve, all its possible capabilities and applications are yet to be discovered (Whitfield, 2022).

1.2 The four types of Blockchain.

When a firm is planning a Blockchain solution to fit its supply chain demands, the critical decision that must be made is which type of Blockchain is most suited for the project. Therefore, it is vital to have a thorough awareness of the various types of Blockchains. It is worth mentioning that not all Blockchains are suitable for handling supply chain data (Wegrzyn and Wang, 2021). Nowadays, there are four types of Blockchain: i) Public Blockchain, ii) Private Blockchain, iii) Hybrid Blockchain, and iv) Consortium Blockchain.

i) Public Blockchain. This is where Distributed Ledger Technology (DLT) first emerged, giving rise to cryptocurrencies like Bitcoin and Ethereum. It eliminates the drawbacks of centralization, such as decreased security and transparency. DLT distributes data throughout a peer-to-peer network rather than storing it in a single location. Due to its decentralized nature, some form of authenticating data must be used. By using a consensus mechanism, users in the blockchain can agree on the ledger's present state. Two popular consensus techniques are Proof of Work (PoW) and Proof of Stake (PoS) which are explained in the next paragraphs. Furthermore, the public blockchain is unrestricted and permissionless; anyone with internet access can join a blockchain platform as an authorized node. This user has access to current and historical data and may perform mining operations, which are the sophisticated computations necessary to validate transactions and add them to the ledger. No accurate record or transaction may be modified on the network. Nobody can check the transactions, detect errors, or suggest modifications because the source code is often available to the public (Parizo, 2021).

ii) Private Blockchain. A private Blockchain network will only allow participants to join if they have been invited and have had their identities or other required information authenticated and validated. The validation is carried out either by the operator(s) of the network or by a protocol that has been precisely defined and carried out by the network in the form of smart contracts or other automated approval methods. In private blockchains, access to the network is restricted to a predetermined group of users. If mining is possible on the network, the fact that it is private could allow administrators to determine which users are allowed to run the consensus process that determines mining [1] rights and rewards. In addition,

[1] Mining = "Mining, in the context of blockchain technology, is the process of adding transactions to the large distributed public ledger of existing transactions, known as the blockchain" (What Does Mining Mean?, n.d).

a small group of users might only maintain the shared ledger. The owner(s) or operator(s) of the Blockchain has the authority to override, alter, or delete any necessary entries whenever it is needed or whenever they deem it appropriate (Seth, 2022).

iii) Hybrid Blockchain. A hybrid Blockchain is a combination of public and private Blockchain. Therefore, it makes an effort to utilize the most beneficial aspects of both public and private blockchain solutions. In a perfect scenario, using a hybrid blockchain will mean having controlled access while still having complete independence in the network. The hybrid Blockchain can be distinguished from other types of blockchains by the fact that its nodes are not accessible to all users, even though it still provides blockchain characteristics such as security, transparency, and integrity. Moreover, the users can choose who is allowed to take part in the Blockchain or which transactions are made available to the public. This guarantees that a firm can work with its stakeholders in the most productive manner possible and brings the best of both worlds to the table (Geroni, 2021).

iv) Consortium Blockchain. A consortium Blockchains are networks that are made up of existing nodes and have control over which users can access them. Compared to the public Blockchain, this network has fewer nodes, but it is more secure and scalable. Additionally, it reduces network overload and, at the same time, increases network security. Even though it is less transparent than a public chain, there are still certain concerns. Subsequently, it is a kind of network with fewer known users. It uses a method that is based on voting to ensure that there is very little latency and that the speed is outstanding. Every node in the network is able to record the transaction, but it is unable to individually add blocks. On the other side, before it can be added to the network, every block added by another node must be checked for accuracy. This enables more interaction and innovation to take place. Finally, it is a semi-decentralized network in which no single party controls it. It is instead awarded to a group of people, or "nodes." It provides network security that is lacking in public chains. It also offers greater control and faster processing and makes the system more secure and efficient (Mathur, 2022).

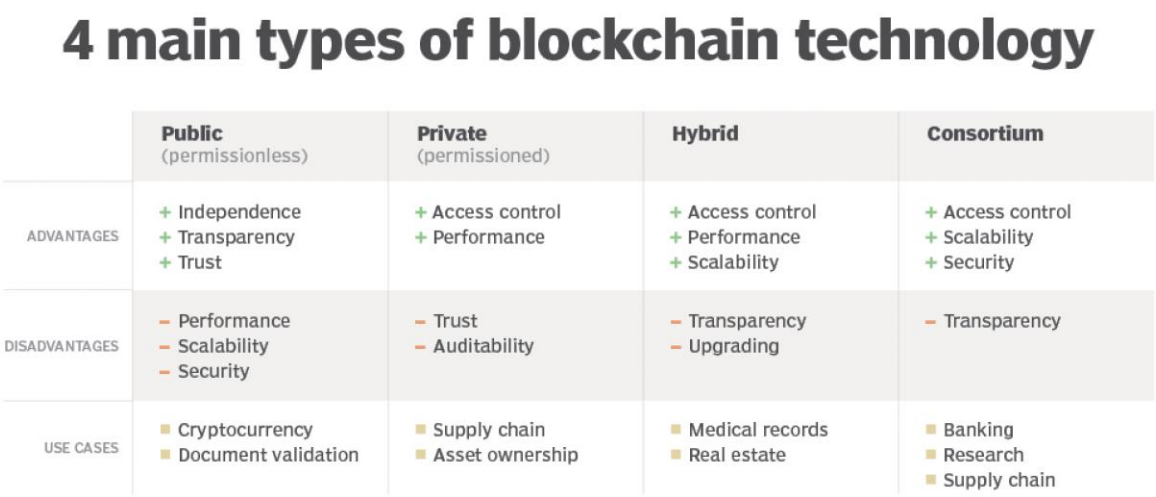

Figure 1: *: The 4 main types of blockchain technology*

(Parizo, 2021)

1.3 Proof of Work.

Proof of Work (PoW) is a consensus technique used to determine which of these network participants, known as miners, are permitted to perform the lucrative duty of validating new data. Miners are paid in cryptocurrency when they successfully validate new data and do not scam the system. PoW is a software method used by Blockchain networks, including Bitcoin to verify that blocks are only considered valid if they require a specific amount of processing effort to generate. It is a consensus technique that enables anonymity in decentralized networks. The word “work” in proof of work is crucial: This system encourages miners to compete to become the first to deal with arbitrary mathematical puzzles in order to avoid system gaming. The winner is chosen to upload the most recent batch of transactions or information to the Blockchain. After other network members confirm that the information being added to the chain is valid and authentic, only the winning miners will receive their reward in cryptocurrency (Napoletano and Broverman, 2022).

1.4 Proof of Stake.

Proof of Stake (PoS) is a Blockchain consensus mechanism used to process transactions and generate new blocks within a Blockchain. A consensus mechanism is a way of evaluating

database entries and securing a distributed database. In this case, the PoS decreases the computational effort required to validate transactions and blocks that keep a Blockchain-based network operational. Moreover, PoS alters how blocks are validated by using the computers of people who own coins. For the chance to verify blocks, the owners put up their coins as collateral. Validators are people who own coins that have been staked. Consequently, validators are selected at random to “mine” the block or validate it. This method uses randomization instead of a competition-based mechanism like PoW to determine who gets to “mine”. It is worth mentioning that PoS techniques may validate blocks using different procedures (Frankenfield, 2022).

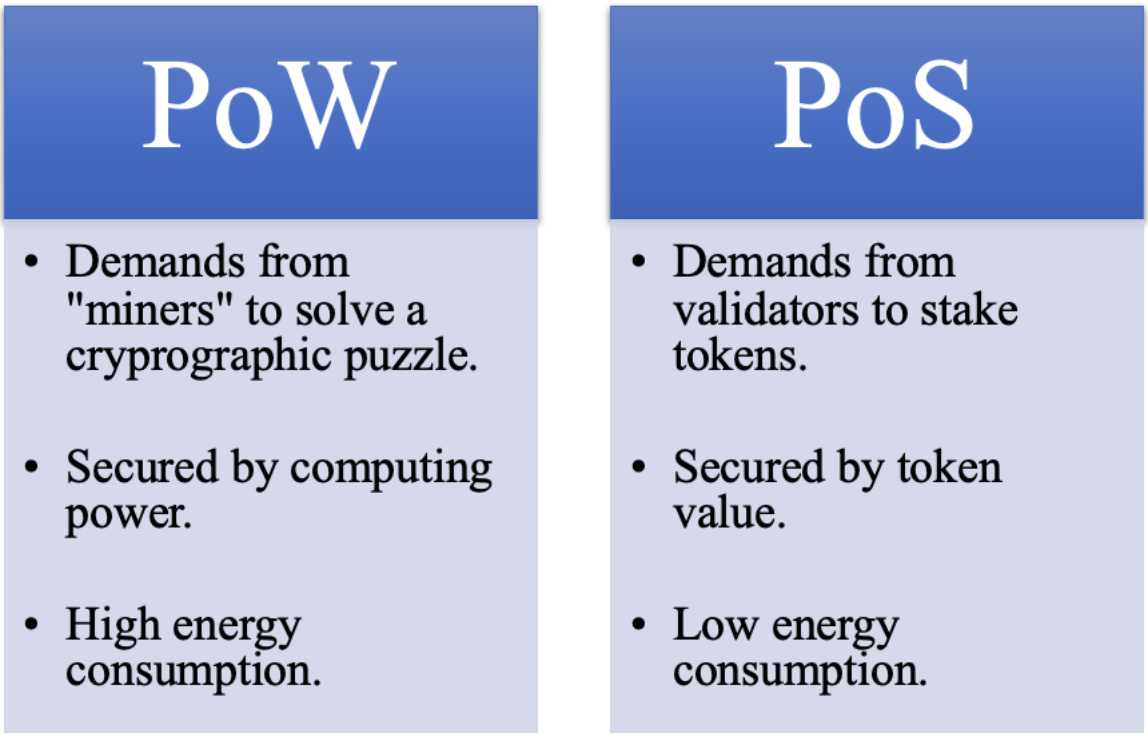

Figure 2: Proof of Work vs. Proof of Stake

(Nibley, 2022).

1.5 The importance of Blockchain in the business environment.

Blockchain technology is advancing quickly and does not appear to be slowing down. Many things that looked inconceivable in the last few decades—like excessive transaction costs, double spending, net fraud, recovering lost data, etc.—turned out to be false. But because of Blockchain technology, all of this may now be avoided (Afreen, 2022). Therefore, nowadays,

implementing Blockchain is essential for any business around the globe when it comes to the digital transformation of an industry. First, it reduces operational expenses. The elimination of intermediaries is advantageous for a company since it not only decreases costs but also the number of points of contact, so enhancing both productivity and expansion. Additionally, transaction speeds have increased to a brand-new level, as a transaction takes seconds to complete rather than a week. If a company can maintain its level of accuracy while increasing its efficiency, then it will be successful (Iredale, 2021). In addition, how rapidly a Blockchain-based information system can process transactions relies on numerous variables, including network traffic and the size of each block. However, according to experts, Blockchain is faster than traditional methods and technologies. For example, Walmart was able to track the origin of sliced mangoes in seconds, a procedure that took approximately a week. Furthermore, Blockchain is also important as it enhances traceability and visibility. It allows businesses to manage inventory levels better, respond to issues or customer concerns, and verify the product's history. Another factor that makes Blockchain implementation crucial for the business environment is the individual control of data. Limits are enforced by blockchain-enabled smart contracts, allowing organizations to choose which pieces of their digital data to share, with whom, and for how long. Last but not least, with the use of this technology, businesses have the opportunity to enhance innovation. Multiple sectors are investigating and putting into practice blockchain-based technologies to address intractable issues and streamline laborious procedures that have persisted for decades (Pratt, 2021).

1.6 Problem Statement.

The demand for digital transformation in ports has grown in recent years, and Blockchain is one of the technologies that can facilitate digital transformation. Major ports of the world have already introduced Blockchain technology for their day-to-day operations. However, it has been identified that the technology has not been implemented and working as it should and therefore ports face several challenges.

An efficient implementation of Blockchain technology is expected to be beneficial for ports in terms of product traceability, access to financing, and cost-efficiency. Therefore, this paper identifies the challenges ports currently face from implementing Blockchain and suggests

possible solutions. Consequently, the following research question needs to be answered: *"What are the challenges of blockchain implementation in ports?"*

To answer this research question adequately, several sub-questions need to be answered:

"What are the legal issues of blockchain implementation?"

"Why is there a lack of trust in the implementation of blockchain?"

"What are the environmental issues of blockchain implementation?"

"What solutions have been tested from the benchmark ports?"

1.7 Motivation.

Various industries, including logistics, manufacturing, healthcare, and IT, can use blockchain technology to address real-time issues. With disruptive technologies such as AI, Big Data, and the Cloud, Blockchain can be a game-changer in various business verticals. It is worth mentioning some predictions that have been made by well-known Technological research and consulting firms. Gartner estimates that by 2030, the use of blockchain technology will result in an annual economic value of about USD 3 trillion. This indicates that by the same year, systems based on the blockchain will govern between 10 and 20 percent of the world's financial infrastructure. In addition, IDC estimates that by the end of 2024, the amount of data spent on blockchain systems worldwide will reach $19 billion (Chaudhary, 2022).

Supply Chains have experienced several benefits from the implementation of Blockchain technology. An example of a supply chain that has benefited from Blockchain is the well-known retailer, "Walmart." Walmart is widely recognized as an industry leader in supply chain management. However, its technological expertise was insufficient to protect it from an issue that has affected the transportation industry for decades: enormous discrepancies in the invoice and payment procedures for freight carriers, which necessitated expensive reconciliation efforts and caused lengthy payment delays. Then, Walmart Canada developed an innovative solution: it used Blockchain technology to build an automated system for handling payments and invoices from and to its third-party freight carriers. The system is

known as DL Freight. Before the implementation of DL Freight, more than 70% of invoices were contested. Currently, less than one percent of invoices contain discrepancies, and these disputes can be easily identified and rapidly resolved. No longer must carriers wait weeks or months for payment; they are now paid on time (Vitasek et al., 2022).

Therefore, Blockchain technology can lessen conflicts, which may be expensive to settle amongst supply chain parties. Supply chains, like the case of Walmart, have the potential to increase transparency in transactions and reduce managerial costs. Therefore, as seaports constitute a significant part of supply chains, it is worth examining the challenges that seaports are facing from the implementation of Blockchain technology and examine the solutions that have been provided by major ports around the world.

1.8 Overview of the paper.

In Chapter 2, the paper gives an overview of the Blockchain applications in the maritime shipping industry, including ports. The legal challenges raised by implementing Blockchain technology at ports are covered in Chapter 3. Chapter 4 explains why there is a lack of trust in the implementation of Blockchain. In Chapter 5, we identify the environmental challenges of Blockchain technology and how these challenges affect the sustainable development of ports. Furthermore, Chapter 6 analyzes the solutions that have been tested from the benchmark ports. Finally, Chapter 7 summarizes the key findings of the research and provides suggestions for further research.

Methodology.

Multiple case study analysis is a research technique that includes examining multiple cases of a phenomenon in order to obtain a more thorough comprehension of it. The cases may be similar or dissimilar, and a comparative approach is typically used to analyze them. In this paper, the multiple case study analysis was conducted through qualitative content analysis in order to investigate the implementation as well as the challenges of Blockchain technology in seaports. The investigation utilized a variety of academic articles, journals, e-books, and surveys to collect pertinent information on the topic. In addition, statistical data were used to provide an overview of the current implementation status of Blockchain technology in the

maritime port industry. In addition, multiple case studies of seaports that were early adopters of Blockchain technology were examined to answer the research question. The specific cases were selected because they showcase a variety of different challenges and applications of Blockchain technologies. Furthermore, they can provide knowledge on how to combat those challenges and overcome the obstacles that come with the implementation of such a state-of-the-art technology.

The investigation of these case studies offers a comprehensive analysis of the implementation of Blockchain technology in the maritime terminal industry. Utilizing multiple data sources and case studies enabled a thorough analysis of the topic. The findings of this study contribute to the comprehension of Blockchain technology's potential to revolutionize maritime ports.

Chapter 2.

2.1 Overview of Blockchain Applications in the maritime shipping industry.

Shipping is the most important transportation industry because it is responsible for more than 90% of global trade. Therefore, emerging technologies play a vital role in the efficiency of maritime transport and, as a result, the global economy. A wide range of government organizations and industries, including the maritime shipping industry, use Blockchain technology. They are incorporating blockchain technology into supply chain activities in an effort to improve their efficiency through, among other things, information flow. The transportation industry in general and the shipping industry, in particular, have been slow to adapt to these changes. Since maritime shipping companies are an integral part of supply chains, they have followed the development of Blockchain, even though a two-tier approach may be seen in action. Liner shipping companies are Blockchain pioneers. They rely on supply chains to i) provide a cost-effective, efficient, and high-quality transport service and ii) implement a vertical integration strategy. On the other hand, bulk freight (dry or liquid) shipping firms have a poor acceptance rate of blockchain technology. This can be linked to Blockchain-related application costs (like development, installation, maintenance, and training expenses (Kapnissis et al., 2022).

Furthermore, as mentioned above, the primary users of Blockchain technology are container shipping companies. With the use of Blockchain, the interested parties can observe the current status of various documents, including sea waybills and customs documents. Connecting all partners and operations involved in the shipping process enhances work and activity management, lowers operating expenses, and makes monitoring easier. The technology is also being used by border and customs officials to give them the data they need to assess hazards. However, as it is a new technology for the industry, players have a tough time understanding the benefits that would result from the effective use of blockchain technology (Blockchain potential in the Maritime industry, 2021).

2.2 Blockchain Developments in the shipping industry.

The implementation of Blockchain technology has a significant impact on the maritime shipping industry. This is because many shipping companies are looking forward to the technology's ability to improve the flow of information across all business categories and make trade-related office procedures more effective (7 Major Blockchain Technology Developments In Maritime Industry, 2019).

2.2.1 Electronic B/L using Blockchain Technology.

A Blockchain-based B/L is a special kind of electronic B/L that utilizes Blockchain technology to create an unchangeable audit trail, complete transparency of business events, and unbreakable confidentiality between business partners (Kern, 2021).

In 2018, the first ever electronic B/L was authorized by one of the top freight forwarders, *Ever Green*, for the transportation of a container, between the Port of Shanghai, China, and the Port of Koper, Slovenia. The electronic B/L, for this container, was issued digitally by using a very secure and trustworthy Blockchain network, the *CargoX Smart Bill of Lading*. It is worth mentioning that the B/L was managed to be transferred in minutes instead of weeks. Moreover, the chances of the Bill of Lading being lost, stolen, or damaged dramatically decreased to near-zero. Furthermore, according to the CEO of *CargoX*, Stefan Kukman, by using the blockchain-based *CargoX Smart Bill of Lading*, shipping companies can decrease their B/L processing and issuing costs by approximately 85% (A day to remember: The first

ever blockchain-based CargoX Smart B/L has successfully completed its historic mission during a trial shipment from China to Europe, 2018).

Nowadays, electronic B/Ls are becoming a standard way to transfer ownership and serve as a contract of carriage. This is because compared to traditional B/Ls, they can be sent faster, at a lower cost, and with more security. Also, with the help of digital signatures, electronic B/Ls can be modified remotely. Therefore, several big shipping companies and dominant maritime trade countries are leading the digital transformation of global trade (Kern, 2021).

Currently, there are several Blockchain-based B/Ls available in the market**.**

2.3 Overview of Blockchain Applications in ports.

Smart technologies have been increasingly and significantly important in recent years in boosting the competitive advantages of ports and shipping operations. Ports use cutting-edge technologies to increase their productivity, safety procedures, vision, and the overall effectiveness of port procedures and shipping. Blockchain technology in ports is used to assist all warehousing activities, transportation activities, shipping terminal operations, and logistics services. With a surge in the volume of commodities moved via ports throughout the world, goods-handling operations at ports must be handled efficiently and with the most advanced technologies, like Blockchain (Alahmadi et al., 2021). Furthermore, the technology might provide a substantial contribution to the organizational operations that take place inside the port, such as queuing at the port gates, ensuring the safety of trailers and containers, and so on. Overall, reviewed projects show that blockchain can be used to improve the following port processes and actions: i) terminal transactions, ii) document workflow tracing, iii) terminal cargo allocations, iv) cargo handling accessibility, and v) inventory certifications (Tsiulin et al., 2020). There is a number of available Blockchain-based technologies which have been widespread in ports.

2.3.1 Global Navigation Satellite Systems.

The Global Navigation Satellite Systems also known as “Satnav”, provide real-time data and location services with the help of satellites. This technology has been adopted by the marine industry as well as ports, and it is believed that approximately 87% of all commercial ships

already use positioning and navigation systems. This is due to the fact that 90% of global trade is done by ocean-going vessels. Therefore, the potential of Global Navigation Satellite Systems for rescue and search operations, coastal navigation, inland waterways navigation, and leisure craft users is gaining more and more attention (Alahmadi et al., 2021).

2.3.2 Quay Connect from the Port of Rotterdam.

The "*Quay Connect"* is a Blockchain-based technology to facilitate customs procedures from The Netherlands to the United Kingdom. The "*Quay Connect"* allows information to be automatically shared with customs officials at ports in the United Kingdom. This enables exporters to digitalize and streamline the export and customs process. The system was introduced by *"Blocklab"* with the help of *"Azarc"* and *"BT."* Furthermore, the platform "*Naviporta,"* to which all parties on both sides of the North Sea are connected, is the foundation of the service that enables the secure and direct exchange of data with UK customs officials. A recent test of this technology showed a few benefits. First, there was a 30% reduction in costs as processing documents and goods was at least 20% faster and more efficient. Furthermore, the use of *"Quay Connect"* provides better insights regarding the status of the cargoes. Finally, as less manual work is required, the risk of errors has been significantly decreased. After this successful test, the digital solution is being used by "*ABC Logistics,"* making them *Quay Connect's* first official customer on the "*Naviporta"* platform. Currently, the service is being expanded to allow the export of other types of cargo and is being made available at all UK ports. Moreover, in The Netherlands, efforts are currently being made to link the service with "*Portbase,"* the *Port Community System*. This is intended to decrease data entry further, resulting in less labor, a lower error rate, and shorter processing times for Dutch enterprises operating in the English market (Donnelly, 2021).

2.3.3 Secure Data Sharing Program.

In an effort to improve cybersecurity, the Port of Rotterdam has introduced its "*Secure Data Sharing Programme"* via its *"Port Community System, Portbase"*. The program is based on the three following critical principles: i) secure processes, ii) secure identities, and iii) secure platform. Moreover, port operators can also benefit from the digital transformation provided by this program. The Port of Rotterdam previously used PIN codes to release containers. However, the *"Secure Data Sharing Programme"* has been linked to this process to ensure

that only authorized enterprises and their staff may do the necessary digital operations and get information within the "*Portbase"* service. According to the Managing Director of *"Portbase,"* Peter de Graaf, "This will help create a secure Port of Rotterdam because the theft-sensitive PIN code will become irrelevant in the port logistic process" (Donnelly, 2021).

2.3.4 T-Mining.

"T-Mining" is an Antwerp-based company that improves the efficiency and security of maritime logistics procedures, including Secure Container Release (SCR). *"T-Mining"* gives businesses simple tools to protect their data by utilizing technologies like Blockchain and concepts like Commercial Privacy and Self Sovereign Identity (SSI). SCR improves the security and reliability of container release procedures for freight forwarders, shippers, carriers, and port terminals. By utilizing Blockchain tokens, SCR offers a digitally safe release process. Furthermore, another feature of *"T-Mining"* is the Secure Document Workflow (SDW). The SDW supports different types of documents and makes it easier and more trustworthy to send and receive documents in a digital environment. Moreover, SDW operates as a network of platforms. Thus, it makes it possible for various document platforms to communicate with one another. *"T-Mining"* makes the container import release process more secure and safer for all employees and clients involved. When Blockchain-enabled tokens are used instead of traditional PIN codes, security and safety improve, and the process becomes much more digital and streamlined (Press Release CMA CGM implements T-Mining's Secure Container Release blockchain solution in the Port of Antwerp, 2022). At the moment, there is a project taking place on a global scale that is focused on Certificates of Origin (Building trusted collaboration, n.d). Approximately 1,500 companies are currently using the SCR, including shipping companies and logistics providers like*: "Hapag-Lloyd", "MSC", "CMA CGM", "DHL", "Katoen Natie", "DSV"*, and *"Kuehne and Nagel"* (Lofvers, 2022).

2.3.5 TradeLens.

"TradeLens" was founded in a collaboration between *"IBM"* and *"Maersk."* It is a blockchain-based supply chain platform that is open and neutral. It makes it possible for real-time information sharing and collaboration across supply chains. This leads to more innovation in the industry, less trade friction, and, in the end, more global trade (TradeLens

Solution Brief, n.d). Furthermore, as it is an open and neutral platform, it increases shippers' awareness regarding the contents, contents, and locations of a consignment by allowing all parties involved in an international shipment to securely and quickly exchange documents and shipment events in real-time. Additionally, platform users can develop new applications that make use of the ecosystem of the platform and distribute them via the *"TradeLens"* marketplace (Jeacocke and Kouwenhoven, n.d). *"TradeLens"* also benefits port operations by reducing container re-handling procedures and enhancing decision making. Excessive re-handling of containers costs money and time, and in the long run, it might hurt the port's reputation. With *"TradeLens,"* a port can use information from upstream partners in advance in order to improve asset and yard management. Also, with aggregated and anonymous client identifiers, there is less need to re-handle containers, which makes stack placement more efficient. Finally, the technology offers secure and trusted real-time data to decrease variability and peak loads, leading to better decision-making (Accelerate your move to a fully digital port, n.d).

2.3.6 PortXchange.

"PortXchange" was introduced from *"Pronto"*, a collaborative platform for terminal and ship planning. The Port of Rotterdam has been using *"Pronto"* since 2018. After the platform's enormous success in the Port of Rotterdam, it was decided to make it accessible to ports worldwide. In 2019, *"PortXchange"* was set up as an independent company. The main goal of *"PortXchange"* is to promote cooperation between ports and shipping firms to achieve lower CO2 and NOx emissions and just-in-time sailing (Our Story, n.d). *"PortXchange"* offers several digital solutions, including *"PortXchange Shiptracker," "PortXchange Synchronizer,"* and *"PortXchange PilotTracker."PortXchange Shiptracker"* is mainly offered to vessel and cargo owners, freight forwarders, and operators, as it provides ETA forecasts up to three weeks in advance, live terrestrial and satellite tracking, and a port call vessel list.*"PortXchange Synchronizer"* is suggested to port authorities, shipping lines, carriers, terminals, and agents. Its main goal is to streamline operations and reduce CO2 emissions by optimizing the entire port call procedure. *"PortXchange PilotTracker"* is provided to pilot organizations, port authorities, and marine exchanges. This digital solution provides streamlined communication by providing the port community and clients with

timely pilot scheduling and vessel movement data (Digital solutions for predictable and sustainable shipping, n.d).

Recently, *"PortXchange"* introduced a new Blockchain-based product, the *"ContainerXchange." "ContainerXchange*" is a neutral marketplace for purchasing, selling, and renting shipping containers. Users can search for containers, handle invoices, and negotiate deals in a single platform. In addition to that, customers can efficiently track their containers by only using the number of the B/L. Moreover, as there is a strict background check for each platform user, *"ContainerXchange*" promises to be transparent, legitimate, and trustworthy (Blockchain shipping: What is it and why is it important?, 2022).

2.3.7 DAKOSY.

The Hamburg-based *"Dakosy"* and *"dbh Logistics,"* which both concentrate on port community systems, have developed a Blockchain-based solution for the release of import containers which was made available in late 2021. This Blockchain solution aims to digitalize and standardize the release process for import containers in the ports of Bremerhaven, Bremen, Hamburg, and Wilhelmshaven. The suitability and practicality of this technology have already been verified by the *"IHATEC"* research project *"ROboB."*Furthermore, according to Holger Hübner, Head of Port Solutions at *"dbh Logistics,"* and Dirk Gladiator, an authorized officer of *"DAKOSY,"* everyone's workload is significantly increased by the manual method, which requires parties to have bilateral conversations about each container in order to coordinate authorizations and empty container returns. Thus, introducing this Blockchain technology will increase the efficiency and productivity of German ports (Dakosy and dbh digitalize the release process for German Ports, 2021).

Chapter 3.

As described in Chapter 2, the correct implementation of Blockchain technology can be beneficial for shipping companies and ports because it increases efficiency, reduces operational costs, increases trade, and because of its automated procedures, Blockchain also reduces lead times. While Blockchain technology has the potential to change business

operations and commercial transactions of shipping companies and ports, there have been identified several legal challenges that need to be addressed for the correct implementation of the technology (Lasmoles and T. Diallo, 2022).

The legal systems worldwide were not intended for Blockchain technology. The few regulations that attempt to control blockchain technology focus on cryptocurrencies rather than the blockchain technology itself. The international character of the shipping industry introduces an additional barrier: verifying that the new technology is legal in all applicable jurisdictions. The distributed ledger of blockchain is designed to share its data across multiple states. This raises questions regarding data protection policies and antitrust regulations. In addition, culpability is unclear if the system fails due to decentralization. Until major jurisdictions overcome these challenges, they will restrict the international application of Blockchain technology (Gardner, n.d).

3.1 Jurisdictional and Governing Law Issues.

The lack of governing law or a regulatory framework is a challenge for the maritime industry because of the possible legal implications as well as the fact that it creates obstacles to the adoption of Blockchain technology. In the absence of regulatory frameworks, the interested parties believe that the use of Blockchain is dangerous, and regulatory authorities have little incentive to engage or set standards or rules since Blockchain is so rarely used in the maritime industry. Among other concerns, players in the shipping industry are concerned about the necessity to govern blockchain technology in terms of data ownership and usage. In addition, key stakeholders are worried about the *"EU's General Data Protection Regulation"* (GDPR) and the industry's ability to handle and own customer data. Concerns have also been raised by stakeholders in the shipping sector regarding jurisdiction and the uncertainty of how disputes, should they arise, would be resolved. The use of Blockchain in enforcement by regulators is not without difficulties and restrictions. These concerns for a public, permissionless platform include questions about which transactions are enforced in the event of a *"hard fork"* (split), resulting in two forks with unique transactions and data. In the case of Blockchain systems, which lack key features like immutability and decentralized consensus mechanisms, regulatory bodies might not be sure that the ledger entries have not been modified. This would result to a big problem if data from blockchain systems were used to make sure people were following the rules, and the users and administrators of the

platform were the same people who could be charged fees or face other penalties for not following the rules (Green, Carr, Winebreak and Corbett, 2020).

3.2 Force Majeure.

When outlining force majeure provisions, the contractual parties may wish to define explicitly whether Blockchain-related issues, such as smart contract failure or compromise of a party's access to the Blockchain, constitute a "force majeure" event upon which a party may rely to avoid performance under the contract. If such issues are mentioned as force majeure occurrences, the parties should consider adding a clause that a party cannot claim force majeure for issues caused by its own inability to maintain industry-standard preventative measures (Casper et al., 2021).

3.3 Land Registry.

Nowadays, the landlord port model dominates in larger and medium-sized ports (e.g., Port of Rotterdam, Port of Antwerp, Port of New York, etc.) (Alternative Port Management Structures and Ownership Models, n.d). In this port model, the port authority retains control of the land while leasing infrastructure, especially terminals, to private operating businesses. The most typical type of lease is a concession agreement, in which a private organization is awarded a long-term lease in return for rent that is typically proportional to the size of the facility and the amount of capital required to construct, remodel, or expand the terminal. Additionally, the private operator must provide terminal equipment to meet operational standards (Rodrigue, 2020). As the average lease duration for maritime cargo terminals ranges from 15 to 25 years, in many jurisdictions, companies that lease port infrastructure for so long must be registered at the Land Registry (Richardson, 2017). Blockchain technology has the potential to facilitate this procedure, however, there have been identified a number of issues.

First, a legal agreement is necessary to be issued since all of the property output is allocated at the beginning of the transaction. The output's specifics are associated with the original owners as recorded in the land registry system. Furthermore, the records must be stored separately in a different location. To strengthen the legitimacy of documents, documentation procedures must be standardized. The document can only be submitted and utilized in other

organizations once it has been approved and verified. In addition to that, data protection and portability regulations are needed to make it easier for land registries to be utilized. Additionally, the land registry contract's digital signature is not subject to the same legal standards as other contracts because it demands perfect authenticity. Another important challenge is the verification of a stakeholder's identity. The public is very interested in making sure the stakeholder is who they say they are. To protect property rights, the land-titling Blockchain-based system needs to make sure that stakeholders are properly verified. There are numerous stakeholders in land registries, including investors, government authorities, sellers, and third parties. During a land transaction, stakeholders must guarantee that all parties comply with the applicable laws. This number of stakeholders would require an enormous amount of information. Consequently, data governance issues and scalability must be overcome. Another major challenge is that Blockchain networks fail to follow the principle of identity. Since Blockchain technology is considered to be reliable, identity principles must be followed for users to be able to manage their own identities. Many of the systems for keeping track of land do not support the principles of identity. Finally, the Blockchain-based land registry is dependent on the private key of the holder; nevertheless, the majority of holders are less likely to recall or lose their *cryptographic keys*[2], making it impossible for them to claim ownership (Shuaib et al., 2022).

3.4 Privacy of data.

Blockchain is a public ledger that is viewable and accessible by everyone. It is a vital component in many situations, but if it is used in a sensitive context makes, it a liability. Blockchain technology has a long way to go before it is widely adopted. The ledger must be redesigned so that it has restricted access and is only viewable by those who are permitted to do so (Mitra, 2019).

In addition to that, Blockchain also needs to comply with the GDPR. Although blockchain has been praised as a failsafe solution for protecting private information, there are worries that it can intrude. Most significantly, while storing information, blockchain creates problems for legal applications. Any data that is entered into the blockchain is allegedly regarded as

[2] Cryptographic key: *" A key is a string of characters used within an encryption algorithm for altering data so that it appears random. Like a physical key, it locks (encrypts) data so that only someone with the right key can unlock (decrypt) it"* (What is a cryptographic key?, n.d)

permanent. Because of this characteristic of blockchain technology, a blockchain is sometimes referred to as being immutable in nature. Moreover, because of Blockchain's immutability, the transactions in each Blockchain block contain the preceding or predecessor block hash, resulting in the development of a cryptographically secure chain. This attribute makes it almost impossible to alter the chain, as doing so would invalidate all subsequent blocks. Considering the criteria of the GDPR of the European Union, the very nature of Blockchain's protection resides in the privacy required to secure personal data. Blockchain also defies the *"Data Minimization"* principle of GDPR, which states that only the data necessary to achieve a specified purpose should be collected. Problems between GDPR and Blockchain continue to arise between data subjects' rights to rectify, modify, and delete data and Data controllers, the Data processor's unique proof, and Blockchain requirements (Suripeddi and Purandare, 2021).

3.5 Limitations of Smart Contracts.

Supply chains, including ports, typically suffer from paper-based systems where forms must go through several channels to receive approval. The lengthy process makes fraud and loss more likely. By providing to the parties involved in the chain with an accessible and secure digital version, blockchain can eliminate these concerns. Inventory management, payment automation, and task automation are all possible with the use of smart contracts.

However, several challenges have been identified in using smart contracts. Firstly, modifying smart contract processes is very complicated, and any error in the code can be costly and time-consuming to fix. Secondly, according to the principle of good faith, parties to a contract will deal fairly and not gain unethical benefits. However, using smart contracts makes it impossible to ensure that the agreed terms are met. Furthermore, although smart contracts aim to eliminate the involvement of third parties, it is not possible to do so. Third parties take on roles that are different from what they do in traditional contracts. For instance, lawyers will not be required to draft individual contracts; however, they will be required to comprehend the terms in order to build codes for smart contracts. Finally, smart contracts are sometimes unable to handle unclear terms and conditions since contracts often include terms that are not always clear (CFI Team, 2021).

3.6 Intellectual Property challenges in Smart Contracts.

Before diving into the intellectual property challenges in smart contracts, we must first mention the four phases of the life cycle of smart contracts in the Blockchain ecosystem: i) Create, ii) Freeze, iii) Execute, and iv) Finalize.

i) Create. Contract revision and negotiation form a major part of the first phase. First, the interested parties need to agree on the scope and objectives of the contract. This can be achieved both online and offline. This is identical to classic contract negotiations. All participants need to have a wallet on the Blockchain used to create the smart contract. After the smart contract's content has been finalized, it must be transformed into code (Life Cycle of Smart Contract, 2022).

ii) Freeze. Nodes are set of computers that are spread out over a Blockchain and are responsible for validating the transactions that take place on the network. These nodes are what are known as miners on the blockchain. In order to prevent the ecosystem from becoming overwhelmed by smart contracts, the miners must be compensated with a nominal charge in exchange for providing this service. During the "freeze" phase of the smart contract, both the participants in the smart contract and the contract itself are made visible on the public ledger. The nodes function as a governance board that checks to see if the preconditions for the execution of smart contracts have been met. This locks the digital assets of both parties participating in the smart contract by freezing their associated digital wallets (Life Cycle of Smart Contract, 2022).

iii) Execute. In this stage, the integrity of the contract is validated, and the code is performed by the inference engine of the smart contract environment. The functions of the smart contract are carried out when the inputs for the execution come from the smart oracles and the parties involved. In addition, when the smart contract is put into action, it creates a new set of transactions and a new state. The new information about the state and the set of findings, are put into the distributed ledger and checked using the consensus mechanism (Singh, 2022).

iv) Finalize. After the smart contract is executed, the resulting transactions and revised state information are added to the distributed ledger and confirmed via the consensus process. The digital assets previously committed are transferred, and the contract is finalized to verify all transactions (Singh, 2022).

Contract generation is a necessary step for the use of smart contracts. Users must compose their own code and publicly release it to multiple Blockchain networks in order to create their own contracts. Additionally, smart contracts on Blockchains cannot be modified after deployment because Blockchains are unchangeable.

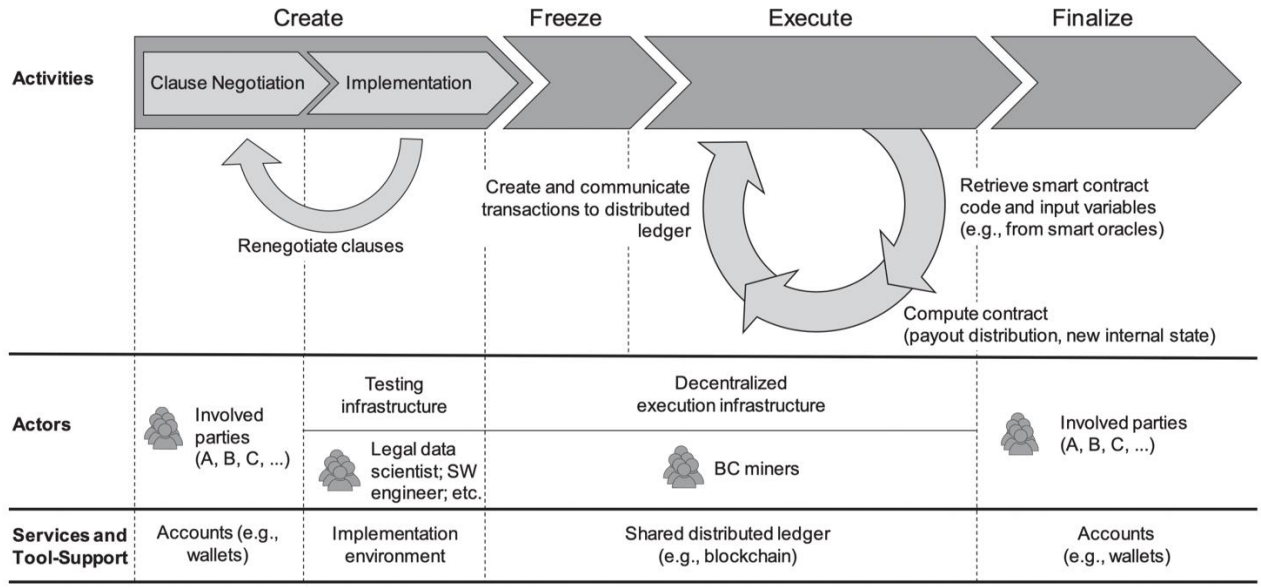

Figure 3: The life cycle of a smart contract: phases, actors, and services. (Sillaber and Waltl, 2017).

Contract generation is a necessary step for the use of smart contracts. Users must compose their own code and publicly release it to multiple Blockchain networks in order to create their own contracts. Additionally, smart contracts on Blockchains cannot be modified after deployment because Blockchains are unchangeable. Therefore, there have been identified a number of challenges.

Regarding functionality issues, smart contracts could overcharge their users as a result of under optimization. These overcharged patterns, sometimes known as dead code patterns, are characterized by dead code, expensive operations, and loops with repeated calculations.

Furthermore, re-entry shows that a stopped function can be resumed in a secure manner. Malicious hackers may use this issue to steal electronic funds. As to deployment issues, the control flow of deployed smart contracts is not immutable, even if the contracts themselves are immutable. A smart contract has the ability to communicate with other contracts. The control flow of a smart contract must be appropriately specified during the contract's creation. Interactions among smart contracts can lead to an increase in the number of interconnected contracts. Even though the execution environment isn't always dependable, the majority of existing techniques concentrate on identifying potential problems with dynamic control flow in programs. Concerning the issues in the execution stage, firstly smart contracts cannot operate in the absence of real-time data. This implies that a smart contract is intended to operate in a secluded setting. In a smart contract, it is an agent that detects and verifies real-world events and transmits this data to the smart contract. Consequently, deciding which oracles are reliable becomes challenging. Furthermore, miners carry out smart contracts one after the other. This means that a miner can't sign a new contract with another company unless his current contract comes to an end. Execution serialization hurts the performance of the system in a big way. Since several smart contracts share information, it is hard to run them all at the same time. As far as the completion stage, most smart contracts and Blockchain networks don't have ways to protect privacy, particularly when it comes to transactions. They are spread out across the whole network of Blockchains. Because of this, everyone can see all the transactions on the networks. Even though some networks utilize pseudonymous public keys to make them more anonymous, most transaction information is still available to the public. Finally, since smart contracts and Blockchain networks are relatively new technologies, they are vulnerable to malicious attacks by cybercriminals. The identification of frauds is particularly important for contract users since it enables them to discontinue their investments early and avoid loss of money (Mathews and Bhowmik, 2022).

3.7 Compliance with financial and tax laws and regulations.

In a world governed by DeFi, transactions are processed automatically, and Blockchain-based smart contracts enable individuals to trade directly with one another without the control of banks or any institutions. The key innovation behind DeFi is distributed ledger technology, which has the ability to alter the structure of our current financial system (Vereckey, 2022). However, several concerns have been identified from the implementation of DeFi.

3.7.1 AML/CFT.

The use of distributed ledger technology for money laundering and terrorism financing is a clear source of concern for regulators. The identity of the parties to a transaction is encrypted even though blockchain is hailed for its transparency. Similar to how cryptocurrencies are used, Blockchain-based solutions that run the danger of being used to launder money or finance terrorism will need to solve this so that regulators are satisfied with the information on hand. This will depend on the level of risk associated with the specific product or service, and anonymity does not necessarily imply a limitless right to privacy. Another factor is the decentralized structure of Blockchain-based solutions. It may be required to show that the questioned solution cannot be utilized to bypass regulations or for regulatory arbitrage. That suggests, for example, that while it is usually not unlawful for a company to base its operations in a less burdensome regulatory jurisdiction, regulators are unlikely to view positively any attempt to arrange a product or service to avoid regulations. As demonstrated by past events, it may initially be able to escape regulatory action, but lawmakers and enforcement agencies will eventually find a way (Blockchain in Financial Services – Compliance and Regulatory Challenges, n.d).

3.7.2 Complicated for collecting taxes.

Transactions involving digital currencies are taxable, but reporting them is challenging, even for the well-intentioned, according to the researchers, because DeFi is mainly constructed on permissionless and pseudonymous Blockchains. In addition, *Barclays* estimate implies that the *IRS* may be losing out approximately $50 billion per year in unpaid crypto taxes due to the difficulty in tracing and collecting tax on DeFi transactions. Furthermore, according to Antoinette Schoar, co-director of the *National Bureau of Economic Research's Corporate Finance program*, In DeFi instruments, tax enforcement is challenging. There are no middlemen with the infrastructure to enforce taxes, verify your identity, and transmit a 1088 tax form or capital gains notification to the IRS. It is extremely inconvenient, even for those who wish to do the right thing (Vereckey, 2022).

3.8 Due diligence requirements.

Already, firms and individual investors are making substantial monetary investments in blockchain technology. This trend is likely to accelerate as commercial blockchain applications become a reality. In connection with these investments, transactional attorneys who are responsible for doing due diligence on the purchase and/or sell side must comprehend blockchain technology and the emerging business models based on the platform. Traditional procedures for due diligence may need to be modified. There will be particular concerns with ownership of data sitting on decentralized ledgers and intellectual property ownership of blockchain-as-a-service services utilizing open source blockchain technology platforms. These concerns must be evaluated considering the business value proposition and competitive entry obstacles (Blockchain: Background, Challenges, and Legal Issues, n.d).

3.9 Antitrust considerations.

The nature of Blockchain technology raises several anticompetitive behavior concerns on the part of those who manage the Blockchain. First, when Blockchain-based business models effectively displace non-blockchain ones, the cross-platform network effects may give one blockchain a measure of market power. As is typical, the argument here is that it is difficult for users or validators to coordinate migrating to higher-value platforms that preserve the network benefits they currently enjoy. For this to be an issue under competition law, however, it would be necessary for those who control the Blockchain to actually be able to control (increase) its price, or to execute a foreclosure plan, or to form a collusive agreement to allow it to raise the price. Alternatively, if the blockchain is unmanageable, it is strategically ineffective (Pike and Capobianco, 2020).

Some have suggested that the use of Blockchain technology by businesses may result in anti-competitive situations, despite the efficiency improvements that could result from collaboration on Blockchain platforms. Distributed ledger networks with certain sensitive information such as price, accessible to competitors may facilitate market manipulation, such as bid rigging and price-fixing. In particular, competitors that form or participate in blockchain enterprises may utilize cost, price, or output data to form illegal agreements. Due to the distributed nature of the ledger, everyone has access to the transaction data of others, which may include prices and quantities. This might give cartelists with a highly effective monitoring tool for detecting deviations from agreed-upon prices, as well as transparent data that enables those who collude to achieve agreements on, for instance, price or market share.

With this level of knowledge, firms in oligopolistic marketplaces can engage in implicit collaboration. Moreover, if a particular private, permissioned Blockchain becomes essential for competing in a market, it is possible that some competitors could be removed from the Blockchain and, as a result, prohibited from competing in the market, depending on who administers the Blockchain. This might happen if relevant market participants coexist in the same permissioned Blockchain and possess the credentials to provide access. In this case, these parties may have an incentive to discourage new companies from joining the Blockchain. Then, competitors would have to compete without this resource. (Arcelus, Yenikomshian and Nocera, 2021).

Chapter 4.

The term "trust" can be interpreted in numerous ways. There is a deep sense of reliance on one another. We can be confident that our friends' good intentions will guide their behavior because we know them well. There's also the kind of trust that doesn't require as much background knowledge or familiarity with the recipient; we don't have to understand their inner workings or history to have faith in their ability to make good decisions going forward. For example, we do not personally know any of the miners in a Blockchain network, but we trust them to comply with the mining protocol. Blockchain technology shifts some of the trust from individuals and organizations to technology. You must have faith in software, computers, protocols, cryptography, and on the network itself. And you must have complete faith in them, as they are frequently "*single points of failure"*. However, when that faith is misplaced, there is little left to do but suffer the consequences. It is possible that large amounts of money can be lost in the event of a hacking attack on the Blockchain-based network or in the case that the login credentials have been lost or misplaced. Furthermore, all funds could be lost if a flaw in the smart contract's code caused it to malfunction. When compared to human interaction, trusting a new technology can be more challenging (Schneier, 2019). As mentioned before, the four main features of Blockchain that make it trustworthy are that it is decentralized, secure, can't be changed, encrypted, and based on a set of rules. The next step is to figure out how these characteristics may affect trust. This chapter, aims to answer the question: *"Why is there a lack of trust in the implementation of Blockchain technology?* (Espelita, 2021).

4.1 Difficulties in Adaptability.

Despite the fact that blockchain technology may be applied to any sector, firms may encounter integration challenges. It is relatively difficult to implement this technology in supply chain operations, for example, because it may take a significant amount of time to replicate and modify supply chains as Blockchains. Blockchain applications may also necessitate the replacement of all existing systems, therefore businesses should take this into account prior to adopting the technology (Cybersecurity via blockchain: the pros and cons, 2017).

4.2 Limited Decentralization.

There is an "illusion of decentralization" in Blockchain technology because the need for governance makes it inevitable that some level of centralization will occur, and structural elements of the system result in a concentration of power (Aramonte, Huang, Schrimpf, 2021). Therefore, by design, Blockchain is not a totally decentralized system. This system is considered partially decentralized. On the basis of simulations conducted on Blockchain, the formation of centralized nodes within the network has been demonstrated. This minor centralization underlines the basic limitations and weaknesses of the existing Blockchains. Although Blockchain is a popular emerging technology that has demonstrated its efficacy in a number of fields, it is not without its limitations (Zarrin, Wen Phang, Babu Saheer and Zarrin, 2021).

4.3 Scalability.

Each transaction must be validated by a trusted central node, with the bottleneck resulting from the increasing number of daily transactions. This is most evident in multichain Blockchains. Multichain Blockchains are private Blockchains utilized for financial applications that necessitate the use of full transaction hashes. The concept of the Multichain Blockchain is to maintain comprehensive security and control over the transactions; hence, communication must be conducted via fully hashed transactions. Using this fully hashed transaction necessitates more storage for communication in the network channel, which would be severely impacted by bottlenecks (Zarrin, Wen Phang, Babu Saheer and Zarrin, 2021).

4.4 Performance issues.

The performance of the latest generation of Blockchains is hindered by a number of factors that make it slow and incapable of scaling for massive transactions. Smart Contracts suffer from poor transmission between nodes and the inability to fully employ arbitrary software programs that are constrained by the immutability of particular blocks. The second problem is *“Forking”*, which is a split that happens when multiple nodes mine the same block at the same time on a Blockchain. This is called a *"fork." “Forking”* creates a delay in the network of more than 1000s. *“Forking”* can also be used to launch a forking attack, in which back doors can be added to the new chain that was made when the two chains split. The third problem relates to Blockchain's performance bottleneck. Long verification times brought on by the block size’s cap of seven transactions are the main source of this performance barrier. A larger block size to provide greater storage would be required to address this issue of a performance bottleneck (Zarrin, Wen Phang, Babu Saheer and Zarrin, 2021).

4.5 CyberSecurity.

The present cybersecurity landscape is characterized by a severe shortage of experts. This difficulty is increased in the Blockchain security area due to the fact that even fewer cybersecurity professionals possess Blockchain expertise or comprehend the new security threats of the growing Web3 decentralized economy (Groopman, n.d)

4.5.1 The 51% Attack.

As previously discussed, mining is a crucial process in validating transactions on a Blockchain-based system and therefore helps it evolve even more. Occasionally, two blocks are mined simultaneously with conflicting transactions. In such a scenario, the block that receives majority acceptance on the network is maintained in the chain, while the other is discarded. Therefore, the outcome could be catastrophic if a group of malicious hackers could seize 51% or more of the mining power. The hackers can then utilize their dominant position to perform fraudulent transactions or even cancel transactions.

Moreover, hackers may be able to rewrite some blocks, but rewriting the entire Blockchain would be practically difficult, although being theoretically possible. Also, the 51% attack and other Blockchain security problems are most likely to occur at an early stage of the chain. When there are not many miners on the network, it might be possible to get 51% of the mining power (Krishna, 2022).

4.5.2 Unconfirmed Transaction Attack.

A Blockchain user is only exposed to a “Finney” or “race attack” if he or she accepts an unconfirmed transaction. “Race attacks” are just a race between two transactions that were sent out at almost the same time. Before the first transaction is added to the Blockchain, the idea is to replace it with a new one that sends the money back to a wallet that the user controls. Furthermore, “Finey attacks” can only be performed by miners and are consequently quite complex and cryptic. A transaction from one wallet to another is pre-mined by a miner into a block. Next, the miners utilize the first wallet to conduct a second transaction and publish the pre-mined block, which contains the initial transaction. This takes a very particular sequence to function, and there is no evidence that a “Finney attack” has been performed (Double-Spend Attacks Examined: Past, Present, and Future, 2020).

4.5.3 Sybil/Eclipse Attack.

A Sybil Attack is a way to try to control a peer-to-peer network by making several fake identities. From the outside, these different identities look like they belong to regular users, but behind the scenes, they are all controlled by the same person or group. Moreover, Sybil attacks could also be used to censor particular participants. A number of Sybil nodes can encircle a node and prevent it from communicating with other trustworthy nodes in the network. On this basis, someone could attempt to prohibit a user from sending or receiving data over the network (Attacks on Blochcain, n.d).

4.5.4 DDoS Attack.

Some believe that DDoS (Distributed Denial of Service) attacks against blockchain networks are unachievable due to the decentralized nature of blockchain networks. However, this is not completely accurate. Traditional DDoS attacks can be used against a blockchain to slow

down its operations, and hackers can use the blockchain ecosystem to execute DDoS assaults. Traditional DDoS attacks are frequently carried out on applications rather than networks. Large network links may have been purchased by an organization, making it impossible to overload them. However, this is of little use if the desired application can only handle a few hundred requests simultaneously. Furthermore, the primary DDoS threat in the Blockchain world is transaction flooding. The vast majority of blockchains have a fixed capacity because they generate blocks with a predetermined maximum size at regular intervals. Everything that does not fit in the current block is kept in mempools[3] for consideration in the following block. If a hacker sends a large number of Blockchain transactions to the network, they are able to flood blocks with spam transactions, causing valid transactions to stack in mempools. If valid transactions are not included in blocks, they are not added to the distributed ledger, and the blockchain is unable to function. Finally, this type of attack can have several consequences including, node failures, software crashes, network congestion, and a bloated ledger (Behnke, 2021).

4.5.5 Double-Spending.

The danger that a DeFi (like cryptocurrency) can be used twice, or more is known as "double-spending". Transaction data within a blockchain can be modified under certain conditions. The conditions permit altered blocks to be added to the Blockchain; if this occurs, the individual who made the modification can claim back spent money. Moreover, double-spending is possible but is more probable that a cryptocurrency will be stolen from an insufficiently protected and encrypted wallet. The "51% attack" is one of the most frequently reported attacks, whereas the "unconfirmed transaction attack" is the most frequently observed (Frankenfield, 2022).

4.5.6 Attacks on Smart Contracts.

If a smart contract's source code contains weaknesses, the parties that sign the contract are at risk. For example, flaws found in an Ethereum-based contract in 2016 cost the parties who owned it approximately $80 million. One of the *"Solidity's"* programming language's

[3] Mempool.= "A mempool or a memory pool is a mechanism to store information on unconfirmed transactions. These transactions are verified but not yet included in the blockchain" (Explained: Mempools and their importance in the Bitcoin mining process, 2022).

common flaws makes it possible for other smart contracts to give control to functions that can't be trusted. This is called a "reentrancy attack." Throughout this attack, contract A invokes a contract B function whose behavior is uncertain. In return, contract B can call a function from contract A and exploit it maliciously (Katrenko and S, 2020).

4.6 Confidentiality.

Anonymization is technically challenging to achieve in a Blockchain. Hence, the data stored on the most popular Blockchain systems are, at best, pseudo-anonymous. This raises confidentiality issues but provides audit trails for law enforcement. A seized computer, for instance, can be used to recreate illicit transaction histories. Furthermore, even if computers that execute transactions on blockchains cannot generally access the data, they can still extract metadata[4] and detect significant empirical recurrences. The data sent to the chain is not immutable but is hard to delete. In addition to that, widely used commercial Blockchains can include permanent data. One could assume that copies (secured by cryptographic algorithms) are misplaced. Additionally, the difficulty of deleting data can be used for illegal activities. For instance, child pornography has been found in the Bitcoin database. Therefore, it is possible to insert private or illegal records into an open Blockchain for the purpose of dissemination or to blackmail (Hilary, 2018).

4.7 Immutability issues.

Once information or code has been added to a blockchain, its inability to be altered is frequently referred to as *"immutability."* On the one hand, a distributed programmable database where everyone has equal access, and no one can change it after the fact on their own has many powerful benefits. A database that cannot be altered and software that cannot be disabled, on the other hand, pose unique and, in some situations, potentially problematic risks. An example of an immutability issue is “the DAO Hack”. The “DAO Hack”, in which a decentralized investment fund formed on the Ethereum blockchain in 2016 raised more than $150 million in cryptocurrencies, is an example of immutability risk. However, shortly after

[4] Metadata = “Data which describes other data. For example, a description of a database in terms of its structure and the relationship between the entities in the database” (metadata, n.d).

its inception, a flaw in the DAO programming enabled a user to transfer about a third of that money to his or her control. Due to the fact that the code was public but "immutable," it was difficult to block the hack while it was occurring without violating the principle of immutability. Furthermore, another risk arises from the active participation as a “miner” or “node” in a Blockchain. Even though this appears like it might not apply to businesses, depending on the technology used, it can be a part of engaging in a blockchain project. This is especially true when a private Blockchain network is used to make a closed ledger that only a few people can see. Miners are in charge of adding information to a blockchain, which might be oversimplifying things. Nodes store this information and share it with everyone else. When we work with data, immutability brings up other concerns. If it's against the law to add or have certain information or data, putting it in a shared database that can't be changed or edited could make the risk worse instead of removing it. If anything is illegal or infringing while stored on a private server or in the cloud, it is difficult to comprehend how distributing it all over the globe in an immutable way reduces or restricts this risk (Understanding the Risk of “Immutable Blockchain Applications, n.d).

4.8 High Development and Operational Costs.

The cost of employing a developer to create a Blockchain network will vary depending on where they are located, how much expertise they have, and the size of the project. Two unique skill sets are often demanded from a Blockchain developer. On the one hand, the developer needs to be familiar with building on blockchain systems like *“R3 Corda”, “Hyperledger”, “MultiChain”, and “Ethereum”*. Additionally, understanding Blockchain-specific coding like *“Vyper”, “Serpent”, “Sophia”, and “Solidity”* is crucial. It is worth mentioning that in the United States, Blockchain engineers charge approximately $100 per hour on average. In North America, the hourly rates range between $150 and $200. Furthermore, based on the consensus algorithm applied, adopting Blockchain can incur substantial electricity expenses. As already mentioned, consensus techniques such as PoW utilize computational power to check the validity of data intended for Blockchain entries. Optional measures include the use of expensive mining equipment and the adoption of alternative consensus techniques, such as PoS. This is closely related to the cost of data storage caused by redundant data. As Blockchain technology expands and adoption grows, more data will be generated, which could result in slowing down the network. Therefore, at

this moment, it is clearly obvious that implementing Blockchain applications would incur significant initial expenses (Obafemi, 2022).

The following table represents the cost percentage with respect to a specific development

Milestone Wise Cost Distribution	In-House
Consulting	10%
Designing	15%
Development	50%
Quality Assurance	25%
Deployment and 3rd party Cost	Private Blockchain: ~$1500/month Public Blockchain: $0.01 / transaction-based for public blockchain + ~$750 for 3rd party
Maintenance Cost	~15% to 25% of the overall project cost.

Figure 4 : Cost of Blockchain Implementation: Process (Takyar, n.d).

4.9 Maturity issues.

Blockchain technology is less than ten years old. This indicates that the technology is new and requires time to mature. Taking into consideration the various consortiums, there are multiple parties attempting to tackle the decentralized challenge with their own unique solution. Similar to any other technological innovation, Blockchain must handle the issue of maturation, which is therefore one of its weaknesses. Furthermore, currently, blockchains are also not maturing in a timely manner. There is still a long way to go until we see advancements in blockchain technology standardization. Currently, there are too many distinct solutions that try to fix the fundamental issues but do not collaborate to standardize it.

Therefore, there is still a long way to go before Blockchain technology is mature enough for businesses to start using it more often (Iredale, 2020).

4.10 Irreversible transactions.

Once a standard transaction has been executed on a blockchain, it is irreversible. This implies that as soon as it is processed, it is written into the network's Blockchain and cannot be altered. There is no authority that can be contacted to cancel or return it. The assets can only be received back if the recipient agrees to send them back. Nonetheless, this must be a new transaction written on the Blockchain and declared irreversible. This is how the Blockchain is developed to assure security. In other words, the process of recording transactions permanently into a block is what makes it secure and avoids the double-spending issue. This method is what makes blockchain technology immensely secure and completely decentralized, eliminating the need for banks and governments to exercise central authority. However, this does not alleviate the numerous problems associated with irreversible transactions. Even though Blockchain networks support that irreversibility is not an issue, modern electronic payments are reversible by their basic nature, which makes them so useful for businesses and everyday users (Watts, 2022).

Chapter 5.

The maritime shipping industry, including ports, is responsible for approximately 2-3% of global greenhouse gas emissions. If nothing is changed, this figure is projected to reach 17% by 2050. Given these estimates, it becomes increasingly vital to reduce this industry's energy consumption and greenhouse gas emissions in response to climate change (Walker and Adams, 2021).

From the early stage of their development to their fully operational phase ports are a collection of pollution sources, such as the use of environmentally harmful materials for construction and their disposal, the usage of machinery and industrial equipment as well as the emission generated by sea-going vessels. In a typical port layout, there are different areas for different operations, such as warehouses, offices, parking lots, passenger buildings, intermodal hub infrastructures, quays, and piers. All of these areas can be viewed as possible

sources of pollution. Furthermore, because ports are constructed to last for a lengthy period of time, their environmental impact can be lengthy. Therefore, it has been identified that port operations have high levels of energy consumption and concentrate high levels of CO_2, NOx, SOx, and PM emissions (Barberi,Sambito, Neduzha, and Severino, 2021).

The implementation of Blockchain technology in ports aims to facilitate port operations to become more sustainable. This chapter examines how Blockchain technology promises to assist the green transition of ports as well as the environmental challenges that arise from its implementation.

5.1 Increasing efficiency.

Due to insufficient management and communication, ships waste a substantial amount of time idling in port, consuming fuel and releasing greenhouse gases. With the use of Blockchain technology in ports issues like, miscommunication, delays, and lack of access to schedule changes can be eliminated. Blockchain grants authorized customers real-time access to data tracking and schedules. This eliminates administrative bottlenecks that have historically delayed business. If this technology can enhance efficiency and more precisely communicate schedules, ships will be able to better plan their arrivals and departures. This decreases emissions, eliminates idling, and saves fuel (Blockchain shipping: What is it and why is it important?, 2022).

5.2 Tracing the quality of fuel.

Tracing fuel quality is another area in which blockchain technology may enhance sustainability. Due to the current climate crisis, all industries are attempting to reduce their carbon impact. The primary cause of the shipping industry's high pollution levels is the sulfur-rich, low-quality "bunker" gasoline used on cargo vessels. The origin and route of fuels are traced using blockchain technology, allowing ships to utilize cleaner alternatives whenever possible. This can be achieved with systems where users have access to reliable and secure fuel information and share it with all network users. In turn, users can validate fuel data quality and assure IMO compliance (Blockchain shipping: What is it and why is it important?, 2022).

5.3 Blockchain’s side effects on Sustainability in the maritime industry.

Although Blockchain technology can provide significant advances both from an economic and environmental perspective, it also has a number of negative effects. Blockchain's high consumption of energy makes its implementation a very sensitive issue in current global warming and climate change discussions. Moreover, Blockchain requires a robust infrastructure in terms of internet connectivity and power/energy availability. For instance, the use of big data necessitates that data centers consume approximately 200 terawatt-hours annually, which is greater than the energy consumption of several nations like Ukraine, Thailand, and Argentina, 50% of the electricity uses for transportation globally, and approximately 1% of global demand for electricity. Blockchain is much less energy efficient than conventional systems, resulting in significant environmental damage and enhancing global warming. A typical Blockchain using PoW demands a tremendous amount of energy. In addition, the existing available Blockchain technology which is available to businesses consumes a significant amount of energy when thinking about the Blockchain’s use and its effect on global warming (Biswas, Jalali, Ansaripoor, and De Giovanni, 2022).

Additionally, considering that blockchain could be used in a lot of ways and that there could be a lot of transactions (millions or even hundreds of millions per year, depending on scale and extent of use), using public Blockchain systems could use a lot of energy and lead to more pollution and greenhouse gas emissions. The already mentioned negative environmental effects contradict the objectives of many stakeholders of the maritime industry, which want to minimize negative environmental impacts and maximize the public advantages of sea-borne transport on communities. These environmental and energy implications undermine initiatives such as the EEDI and the SDGs of the IMO, as well as the Marine Environment Protection Committee roadmap approach to decrease greenhouse gas emissions from sea-going vessels by 50% by the year 2050. Furthermore, because of the various sources of electricity used to power the blockchain system node, the location of all these emissions, and the impacted populations, the maritime industry may be particularly affected by Blockchain's high electricity consumption. If inefficient Blockchain networks are utilized for the shipment tracking use case, electricity could be generated in regions where coastal air pollution is a concern, like China, which in the first few months of 2020 has the second highest number of

"Ethereum" nodes after the US and also primarily relies on coal for the generation of electricity (Green, Carr, Winebrake and Corbett, 2020). The following graph shows that in 2022, a transaction in the "Bitcoin" network use as much energy as several hundred thousand "VISA" card transactions combined (de Best, 2022).

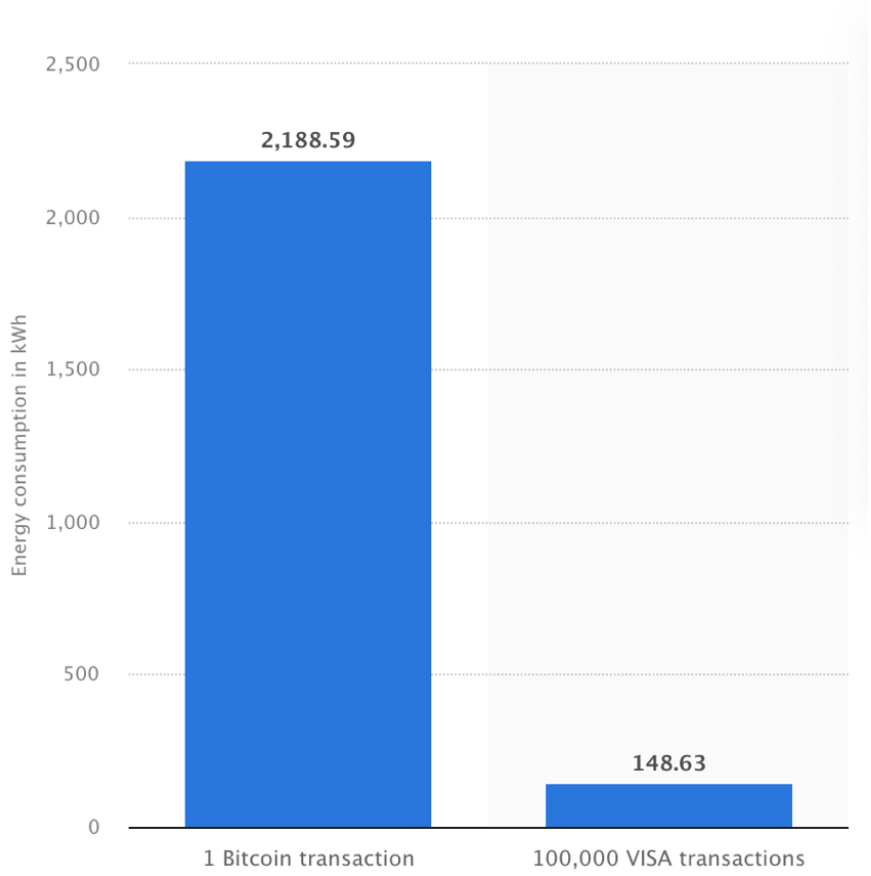

Figure 5: "Bitcoin average energy consumption per transaction compared to that of VISA as of April 25, 2022" (de Best, 2022).

Chapter 6.

6.1 The Port of Thessaloniki.

The Port of Thessaloniki is among the first Greek ports to adopt the bock-chain technology and integrate the TradeLens. The implementation of blockchain technology in the port resulted from the envisioned smart that would simplify the operations to the wider communities (Bechtsis et al., 2019). The TradeLens was developed by TradeLens GTG

Solutions to enhance transparency and secure data exchange. The operational efficiency in the port increased significantly. However, like any other port, they experienced various challenges affecting the desired operational outcomes (Port of Thessaloniki adopts blockchain technology with TradeLens, 2021).

Some of the emergency concerns in the Ports operation included security concerns and legal framework. The parties involved in the contract may assume that they do so, and all the parties will oblige to the contract agreements. Smart contracts may help ensure that the contracts are executed accordingly. One significant concern was the cases where the performance might be frustrated in one way or another. The law of the excuse for nonperformance may complicate the history of the contracts. However, in exploring such issues as identified in this study, it is essential to explore the principles of the contract laws and how they can be bound within the smart contract in blockchain technology, as evident in Thessaloniki Port. The creditors must obtain the damages for specific nonperformance or terminate the contracts. The debtors' liability is always limited as the nonperformance does not directly result from their actions. Also, the debtor may not be accountable for the mistakes by the third party, though he is liable for the loss of goods and so must take further preventive measures.

The interplay between the impossibilities and excuses has previously resulted in complicated rules and exceptions that must be addressed. Modern legal systems have worked on finding solutions to such issues and ensuring a clear attributability of the reason for the non-performance. The art. III - 3:104 DCFR provides the principles and guidelines that should be adopted in the smart contracts in the blockchain technology used in the maritime industry to reduce the impediments to effective performance. There must be a clear definition and distinction between the obligations of results and means. For example, the German contract law was modified to offer excuses besides the impossibilities. The rule indicates that the creditors have no claim to the performance if it is impossible for the debtors or other parties involved. Comparatively, the English law about the *Davis Contractors Ltd v Fareham Urban District Council [1956]* recognizes that frustration can only be applicable in cases where the law recognizes that without the default of the parties involved in the contract, the obligation becomes incapable of being performed because of the prevailing circumstances (Jaswant and Kale, 2021).

The force majeure clause may release a party from the obligation in specific events if they have allocated the risks to a given party. The clause is interpreted as narrowed in some situations and so cannot be invoked if the clause results from the negligence of the parties involved in the contract. Determining the causes of nonperformance in smart contracts has improved since the parties involved have their obligations indicated in the contract agreements through the blockchain technology network. The oracle can detect external factors that could have made it impossible for the parties involved in the contract to execute their roles as expected and outlined in the agreement. The system also offers a simple way of determining the case of nonperformance, which may include bad weather, a strike, or even a breakdown in the internet, among others (Jaswant and Kale, 2021).

6.2 Port of Hamburg.

There is much to learn from the Port of Hamburg regarding security and privacy issues in blockchain adoption in the port industry. The port suffered technical glitches associated with the security and privacy of blockchain technology. The port operates many activities; therefore, introducing blockchain technology would help improve operational efficiency. Also, the port officials indicated experiencing improvements in the documentation and proof of ownership of the goods being transported. The port community system sought to solve the communication problems between the public and private stakeholders in the maritime industry. The study recorded that data security was a significant concern limiting the consensual agreement between the various stakeholders in the maritime industry. Therefore, blockchain technology was implemented to offer solutions to communication challenges (Hackious et al., 2019)

Blockchain technology already has great significance in the logistics industry. Blockchain technology could facilitate data exchange in a trusted and secure environment. The parties involved in shipping can also track the payment progress and check procedures and documents in time. The Internet of Things has brought significant developments that enhance device connectivity among the key concepts. The shipping industry's transportation and supply chain processes need to be geared toward transparency and traceability. The Internet of Things functionality in blockchain technology was adopted in the Port of Hamburg and could offer enormous and significant solutions to some of the current experienced challenges. The records on the goods being transported will be quickly processed upon the agreement at

the checkpoint. The technology will also make it easy to monitor the precise locations and conditions of the goods being shipped. Also, analyzing the goods conditions and other parameters will generate a real-time update that defines whether the conditions indicated are within the acceptable values. The approach will result in less time spent clearing goods in the ports and resolving disputes that might arise. Smart contracts have also been widely explored and indicated as a possible solution to some of the issues related to the legal frameworks in maritime operations (Tsiulin et al., 2020).

Blockchain technologies may be used exclusively within the port areas for security purposes. Theft confirmation in the blockchain ledger could be prevented by having a thorough verification process that ensures that the goods delivered meet digital approval. The security mechanisms can only be achieved through decentralized storage immutable to changes and high diversity users (Panos et al., 2020)

Blockchain technology is a new development in the shipping industry and could be adopted and applied in various lines of operations. Technology might have a significant role in handling documents inwards and outward the port areas. Therefore, the review of the study conducted by Jaswant and Kale showed that blockchain technology was effective in terminal cargo allocations, inventory certification, terminal transactions, and cargo handling accessibility. The study also emphasized that integrating the Internet of technology in the Blockchain could present long-term benefits to maritime port operations (Jaswant and Kale, 2021)

On the other hand, the Port of Hamburg also experienced significant challenges in terms of adaptability. There was a need to install new technologies that would cost much money. Additionally, various regulations had to be implemented to favor digital financial transactions. The concept of the financial process is one of the most significantly contested in terms of law and regulations. The study also reported that the global supply chain environment involves various parties who may be required to follow policies and regulations. The study indicated that the financial transactions in the Blockchain use alternative money, and there is no direct evidence from the government to support the transactions. Adopting cryptocurrency as a form of payment still requires a lot of government regulations and harmonization. The case studies from Japan, Estonia, and Belorussia indicated that cryptocurrency could be a financial instrument and thus making it difficult for companies to

transact, especially when they are from different parts of the world. The shipping industry's blockchain project aims to create an initial coin offering and analog of the initial public offerings in tokens. The blockchain project depends on the internal currency and the mining processes (Jaswant and Kale, 2021).

6.3 Rotterdam Port and Response to Security and DDO Attacks.

The Port of Rotterdam introduced Quay Connect, a new blockchain technology that would make the customs procedures from the Netherlands to U.K. automated. The Quay connect was initiated by the Blockbab and developed alongside the Azarc and blockchain technology. Some advantages of blockchain integration in the port included cost savings, less manual work, and reduced error. In addition, the port experienced better insight into managing its cargo status. Furthermore, the port launched the Secure Data Sharing Program through the PCS Port base, which would help fight the issues linked with the DDO attacks. The program also aims at making the wide-chain approach more secure. Blockchain technology offers more significant opportunities to the industry (Kanduza, 2022).

On the other hand, there are a series of concerns raised with the distributed denial of service attacks which could alter the transaction process and inconvenience the parties involved. Security features are critical considerations that must be clarified before adopting blockchain technology as a mainstream operational strategy for maritime ports. The study explored the concept of DDOs and the mitigation measures that could be adopted to enhance the realization of the expected outcomes in blockchain technology implementation.

The TradeLen has processed over 225 million data-sending incidences covering container shipping, custom documentation, and warehousing time. Also, the Valencia Port announced its plan to create an intelligent port using blockchain technology. It was suggested that blockchain technology could improve logistics on a global scale and help make the ports without papers, reducing the time spent on maintenance. Some successful collaborations on blockchain technology have been indicated in the port of Rotterdam, which teamed up with the ABN AMRO port and the I.T. in subsidizing the Samsung tests of the Blockchain for shipping (Panos et al., 2020).

6.4 Port of Valencia.

The adoption of blockchain technology has been used successfully by companies in the shipping industry to keep trade finance documents. Significantly, many ports successfully managed to create the smart bill of lading. The Port of Valencia was reported to have joined the Tradelens project, which IBM and Maersk initiated in applying blockchain technology in the supply chain. The port is among the largest in Europe with extensive activities and seeks to become one of the largest three ports. The port has been among the early adopters of blockchain technology. Other than Valencia port, 20 other ports are using the Tradelen technology. Examples include the PSA Singapore, the Patric Terminals, the Port of the Biboa, Port Connect, and the Modern Terminals in Hong Kong, among others.

The Blockchain allows multiple partners, including forwarders, terminals, shipping companies, and customs, to access the project in real-time. Also, blockchain technology allows the shared view of the transaction as it protects the privacy and the confidentiality of the data transmitted through the system. The ports can also collaborate between customers and importers, government agencies, immigration, and other statutory bodies. The documents in the blockchain network are traceable and can be audited under the business document beta module referred to as ClearWay (Jasper, 2018).

6.5 Cost Reduction in Block-Chain Technology.

Many ports worldwide have started to experience the benefits of blockchain technology. The U.K.'s leading port operator, the Associated British Port, has also signed an agreement with digital logistics to allow marine transport international to create a blockchain network for port logistics. The integration ensures that the time spent processing the shipping documents is addressed.

The study by Jovanovic et al. indicated that the blockchain ecosystem offers decentralized solutions for digitalizing container records on the transition history. The digitalization of the physical workflow has been demonstrated to red transaction costs and enhance transparency. In addition, blockchain technologies have a data layer that can be used in the marketplace for complementary applications and create additional values for all platform contributors. The

study also recognized the unique challenges presented by the blockchain environment. However, proper remedies have already been implemented to improve the experiences with the new technology (Jovanovic et al., 2022).

6.6 Trust and Safety Concerns.

The blockchain initiative was founded as a response to the global lines to the Maersk Line Tradelens headed by CargoSmart, which works to provide solutions to the shippers and terminals intending to use blockchain technology. The findings from the piloting report showed that technological developments have far-reaching impacts on the global supply chain. Effective platform governance ensures industry-wide adoption of the technology and its success. The blockchain platform architecture, by its design, has an on-chain technology of governance features; though, they are insufficient in establishing the level of trust needed to convince the prospective global supply chain adoption.

The findings on TradeLens, a blockchain-based ecosystem, explored the role of leadership in the effective operation of blockchain technology. The study indicated that TradeLen provides an efficient and standardized platform for exchanging information in the digital medium. In addition, the study reported that digitalization allows companies to handle and redirect their efforts to manage burdensome administration and create more value in their activities. In addition, the development has created a foundation for the ecosystem leverage and benefits the actors in the marketplace.

The digitalization of the workflow also creates end-to-end visibility that targets the entire shipping ecosystem. The ability to have visibility in areas initially considered black spots is a significant development in the shipping and maritime industry. The sentiments obtained from the project echoed the need for the global international team to have a synchronized leadership approach that would promote blockchain technology in modern world maritime ports. The study also indicated that the problems experienced in the platforms such as INTTRA, GTN, and Cargo Smart would be addressed by the new developments in blockchain applications in maritime ports. The study indicated that the former actions were marred by a lack of data transparency and limited accessibility. Also, the study showed that most digital platforms fail because the ecosystem is not complete with connecting all the players and allowing them to share data confidently (Jovanovic et al., 2022)

The TradeLens promised significant improvements in terms of operational efficiency in the maritime industry. The findings from the case study on the TradeLens provide meaningful implications for the potential presented by blockchain technology in improving operations in the marine sector. However, there are persistent limitations that are still recognized and could take a longer time to address. Analyzing the pros and regulations of the blockchain technology application provides a balanced perspective for discussing the application and its relevance in the modern shipping industry. The research contributes to understanding interoperability governance and how it could be used to increase perceived usability. The study indicates the importance of strengthening digital standards to improve the adoption of blockchain-based platforms in maritime ports (Kapnissis et al., 2020).

6.7 Wismar Seaport Case Studies.

The study by Philipp et al. focused on analyzing the experiences and outcomes of the INTERREG, Connect2SmallPorta, and CSHIPP projects. The projects aimed at improving cross-border connectivity and operations in the blue and green transport regions. On the other hand, the CSHIPP project focused on stabilizing transport to enhance clean shipping. The project's progress also helped in understanding the concept of blockchain technology and smart technology. The study also adequately explored the topic of the blockchain smart contracting system. Therefore, based on the findings from the research, the study indicated that the potential adoption of the technology would be context into the charter-party contraction process, the seaport sizes, and how they would adapt to the developments worldwide (Philipp et al., 2029).

The analysis of the concept of the charter party in the contracting process in the single voyage and freight market showed that the Blockchain presented significant benefits. The cargo import characterized the medium-sized seaport of Wismar, located in Germany. Regarding the charter-party contracts, the process occurred in four stages: pre-fixture, fixture, post-fixture, and post-fixture discharging. The fixture stage included the beginning of the charter, where the fixed sale contracts with the suppliers or processes were developed. The charter-party contracting process would involve many actors occasionally; therefore, the case was simplified into a trader or a shipper. At the fixture stage, the shipbrokers sought a suitable

ship based on the indicated freight features and the anticipated shipping time. Depending on the conditions envisaged in the contracts, the market situations and the networker of the shipbroker were determined. The parties involved would then negotiate on the best terms and conditions; the process would take a long time because of the possible counteroffers. The study indicated that the expected standard charter-party forms were used; they included the GENTIME, ASBATIME, and BALTIME, among others. The final phase in the charter process included the post-fixture, where the monitoring tasks were executed. The phase involves monitoring the tasks and controlling the discharge processes (Philipp et al., 2029).

The critical benefits enjoyed from implementing the blockchain smart contracting system included the efficient cargo flow achieved through the Internet of Things application. The GPS shipping data would be collected and exchanged automatically. Also, it was possible for the parties involved in the transaction to sign the agreement through the private key and validate the files and generate copies if needed. The IoT seems to offer reliable and elaborate solutions to the concerns linked to the security of using blockchain technology in maritime ports (Philipp et al., 2029).

The Wismar seaport handles bulky cargo and would benefit greatly from blockchain technology. The strategies employed in deploying the blockchain technology in the port indicate that it could be replicated in other parts of the world. The dynamics and legal frameworks may vary from one region to another. On the other hand, there is a possibility of limited variations in the other technical and operational efficiency aspects as far as blockchain technology is implemented. In terms of data protection, permission to access the data was granted to specific stakeholders. All the relevant data, including the ledger, were stored in blockchain technology. The study indicated that implementing blockchain technology streamlines the various aspects of port operations. In addition, smart contracts would allow the check of actions and transactions, leading to a more robust integration of the financial service providers in the supply chain process (Philipp et al., 2029).

The study reported that the administration costs were reduced by about 2%. Other than the direct cost reductions, the time savings could also be accounted as additional cost savings. The voyage charter commissions vary between 1% and 5%; implementation of the blockchain technology reduced the cost in equivalent percentages. Also, the personnel required to handle the shipping processes would reduce significantly. The control checks

ensured that the real-time data would be transmitted through the integration of the Internet of Things, the sensors, and the trackers (Philipp et al., 2029).

Another study explained that smart contracts as computer codes that would be run on blockchain technology and represent transactional protocols. The study indicated that the smart contracts were self-executable permanently (Lasmoles and Diallo, 2022). While the codes cannot be changed, it was possible to have other agreements and contracts that the parties agreed on, and this would help solve the issue of immutability. The records would be stored in the network and cross-referenced. The case scenario is similar to the physical contracts since once a contract is made, it cannot be altered; though, there is always room for creating new ones with new terms (Bavassano et al., 2020).

The discourse on the possibility of adopting blockchain technology is engrained in the ability of the information to be reduced or replaced with the implementation of blockchain technology. The study explored the processes through which smart contracting and Blockchain technology could be used in facilitating the implementation of collaborative logistic structures. Smart contra can read and write from the Blockchain. Also, they ensure that a given transaction or action is automated, easing the validation of the completion of the contractual agreements. The contractual agreements about the legal principles are coded as transparent algorithms and can be stored on the decentralized system for easy access by all the parties involved. The characteristics of blockchain technology affect smart contracts and make them more secure from any form of distortions and manipulations (Bavassano et al., 2020).

Smart technology is not a contract based on positive law; instead, it is a computer codification and may not be a self-sufficient agreement. Therefore, proposals have been made to enhance the legality of such agreements to make future commercial activities more binding to minimize the high costs associated with judicial interventions and contract drafting. According to the projection by IBM, blockchain technology would reduce the costs in maritime ports by about $300 per container transported. The new technology would also solve the complexity of international maritime trade (Bavassano et al., 2020).

Effective legal regulations are critical for managing business risks. The study indicated that the safety rules, such as the International Regulation for Preventing Collisions at Sea of 1972

of the SOLAS Convention of 1974, ought to be incorporated into the legal framework governing blockchain technology operations in maritime ports. The amendments of the SOLAS convention in 2014 and the subsequent 2016 changes indicated that the weight of each container must be weight before loading. Furthermore, the standards offer flexibility suitable for adopting the consortium-type Blockchain (Lasmoles and Diallo, 2022).

6.8 Port of Antwerp Case Study.

Different goals and purposes influenced the implementation of blockchain technology in the various ports. On the other hand, IoT and considerable data utilization seem to be expected in most maritime ports. The city of Antwerp in Belgium is an example of the European IoT leaders. The economic activities in the port increased significantly with the development of blockchain technology. The port is ranked second in terms of the largest ports in Europe after Rotterdam (Blockchain smart port case: container release in the port of Antwerp, 2021).

Blockchain smart technology piloting in Antwerp involved using the NxtPort and other digitalization. The NxtPort technology was used to collect and pool data from the various supply chain stages. The project involved a data utility platform that would contain data from all the containers in an end-to-end logistic chain. The analysis of project would be analyzed in terms of efficiency. However, some issues remained significant in blockchain technology. Some of the issues identified included the data silos and the challenges in the supply chain.

The ambitions of Maersk and IBM partnered with T-mining and Antwerp. Blockchain technology would allow the identification and pick-off of the trucks automatically. Before the integration of blockchain technology in the port, the Alfapass pin code was generated for every container that passed through the port. In addition, the carriers would be subcontracted to transport the containers to another haulage company. However, with the installation of the Blockchain, the need for pins and passwords was eliminated (Chang et al., 2020).

6.9 The Port of Singapore.

Like any other country implementing blockchain technology in the maritime industry, Singapore experienced a series of challenges. Some difficulties included the cost implementation, lack of data privacy, and experienced partners. Also, there were issues with

scalability and the lack of adequate knowledge of blockchain technology. The study reported that implementing blockchain technology can be expensive; therefore, organizations need adequate financing to support the cost. The study said that most of the organizations in the maritime industry are experiencing financial challenges that could limit their capacity to implement the B.T. While various challenges were reported in the blockchain application in the maritime sector in Singapore, the study also reported that critical success factors included staffing training, ease of the local legislation, professional consultation, and sufficient capital (Perkušić et al., 2020).

Regarding policy implementation, policymakers must develop plans and approaches to encourage organizations to implement blockchain technology. Regulations and legislation regarding blockchain adoption will ease the technology adoption; the legislation must be at the local and international levels. Perkušić analyzed the potential impact of blockchain technology on intelligent contracts in the shipping industry. The focus of the study was on the possible legal framework and regulations. Also, the study introduced the concept of the smart contract, which was introduced by Nick Szabo, who defined the concept as a computerized transaction protocol executed in terms of contracts. The study also indicated that intelligent contracts must always follow legal procedures. The contracts must be defined in terms of the conditions and chains of events that all parties must meet. Shipping industries face challenges moving goods from point A to B from the many parties involved in the transaction (Perkušić et al., 2020).

Similarly, the entities involved in the transactions must have contracts or charter parties. For example, the study illustrated the regulatory requirements based on tanker transportation, which needed many intermediary papers works. Having many intermediaries in the shipping process results in high costs and delays in transportation.

Effective utilization of blockchain technology can help address the issues and improve the experiences of companies in the maritime industry. Perkušić et al. indicated that the shipping industry is divided into various segments, so ports and nations have to find a solution to harmonize the operations. Regarding the 2015 Israel's Wave Company, which implemented blockchain technology, significant concerns, and data trust issues exist. Hong Kong's Chain of Things engaged in extensive research that would help improve the operations in maritime shipping significantly. They introduced the sharing of the Internet of Things through

blockchain technology. Also, sensors were used in collecting information, and data would be transmitted to various parties. In 2017, the most significant breakthrough in blockchain technology was recorded when the giant Maersk and its partner IBM announced the blockchain solution for digitalized international trades. The technology could cut costs and fraud, among other risks associated with handling physical documents. The blockchain smart contract was introduced to help combat cargo fraud and fraud charges and simplify the processes (Perkušić et al., 2020).

Furthermore, the study analyzed the role of the International Maritime Organization in blockchain implementation in the maritime industry. The three contractual agreements involving the Danish shipping conglomerate and Maersk revealed detailed information on the usefulness of the blockchain platform in the shipping industry. The agreements involved using the Internet of Things and Azure Cloud solutions in the digital transformation and improving the processes and transactions undertaken with blockchain technology (Perkušić et al., 2020).

6.10 The Hainan Free Trade Port- Case Study.

The study by Liu and Wu explored the use of blockchain technology in the Hainan Free Trade Port. The study gives a background account of the factors that led to the adoption of blockchain technology in the maritime industry. According to Liu and Wu, China's shipping industry faced numerous problems, including too many paper documents. The study indicated that the introduction of blockchain technology revolutionalized the operations in the port. The cost of trading the containers and goods being transported was also reduced (Liu and Wu, 2020)

Hainan is the largest tropical island in China, with many natural resources and eco-friendly living environments. China introduced many policies to make the region a free trade zone. The number of cargo passing through the port also increased significantly. Therefore, there was a need to introduce an affordable and efficient mode of operation that would allow the handling of multiple cargoes without much strain (Xiu and Lu, 2022).

The ports are among the most crucial hub ports in the Belt and Road initiatives, with three districts; the Xiuying, Xingang, and the Macun. The other port served by the Hainan FTZ is the Sanya Port Hub. The two ports had not adopted modern technologies in their operations. So there was a need to develop an efficient mode of operation that would facilitate easy transition and clearance of goods at the port. Introducing blockchain technology in the Hainan would improve the port's security features. Furthermore, the technology would create a safer and more trusted financing environment (Liu and Wu, 2020).

Limitations.

The limitation of this research paper is the inability to fully triangulate and collect enough data to attain saturation. Due to time constraints, it was challenging to conduct interviews as it was initially planned in order to investigate in more depth the research question. Consequently, it was unable to thoroughly investigate all perspectives and experiences associated with the phenomenon of interest. In addition, the lack of participants prevented from reaching data saturation, which may have diminished the depth and richness of the findings. Future research should allocate sufficient time and resources to data acquisition to ensure triangulation and saturation.

Another limitation is that the adoption of Blockchain technology in ports is still in its early stages as an emerging technology. As a result, publicly available data on the subject are limited. While various but not enough case studies on the application of Blockchain in specific ports have been conducted, further research is required to grasp the technology's outcomes properly.

Chapter 7.

The various concerns against blockchain technology could limit its adoption in the maritime industry. However, like any new technology, bottlenecks and challenges are expected until appropriate sustainability options are developed. Blockchain technology presents various potential advantages, so addressing the concerns could improve maritime ports' efficiency and operational profitability. Continuous research is still underway to discover the new and

best methods to integrate the technology into the shipping industry operations. Some of the critical issues identified in this study included the difficulties in adaptability, which is based on the fact that many firms may find it challenging to integrate the technology into their operations because of the cost implications and the technical know-how limitations. In addition, it may be necessary for the adopting companies to replace all their existing systems, which means that the majority could shy off from the technology. On the other hand, while the system's initial deployment may be expensive, companies should focus on the long-term benefits they will enjoy from the initiative. On the other hand, that does not mean they should overlook the other limitations, including the limited decentralization, scalability, immutability, performance issues, cyber security, and confidentiality concerns.

The study by Tsiulin et al. indicated that the rate at which technological developments are experienced exceeds the corresponding rates of developing laws to cover them. Digital transformation requires the shipping industry to adjust and apply digital technology in the best way to realize the desired benefits. It is agreed that the digitalization of maritime commerce needs to be accelerated following the experience witnessed during the Covid-19 pandemic. The emergence and development of blockchain technology and the Bill of Lading have attracted significant attention. There is a consensual agreement the blockchain technology (Tsiulin et al., 2020).

A study reported that the implementation of blockchain technology is highly dependent on transparency and audibility. The decentralization excludes the intermediary parties, which means that the central authority stores all the data and authenticates the transactions. Blockchain technology means people can establish direct connections between the targeted end users. The study aimed to determine the successful implementation of blockchain technology in the shipping industry (Perkušić et al., 2020). Blockchain adoption in the maritime industry can expedite containerization and international trade. The movements of containers from port A to B involve various bilateral interactions; therefore, the exchange of goods depends on the bilateral permissions and the transactions between multiple organizations. The study analyzed the conventional transport of flowers from Kenya to the Netherlands in exploring the jurisdiction and governing law issues and how they can be addressed. Blockchain technology uses a decentralized and immutable technology distributed into the peer-to-peer network. The study reports that the ecosystem allows the members within the network to access secured data and creates an essential avenue for overcoming the

existing challenges in the CIT. The technology enables partisans to access real-time shipment information and trade documents. It creates an opportunity for eradicating the numerous bilateral information and documentation needed for the shipment of goods. The BT-based platform offers a feature where approvals from various authorities on container sealing and inspections can be done quickly (Balci and Surucu-Balci, 2021).

Custom authorities are some of the key players in adopting blockchain-based platforms. The manual paper permission always creates delays in the cargo release, and this could increase paper costs. The significant benefits realized from B.T. can also be improved by having a system to govern the data transmission between the parties involved in the transactions. One commonly cited limitation in adopting the B.T. is its data ownership and usage governance.

The study also reported the need for a consensus mechanism that will require various parties' contributions to verify and settle the blocks of the transactions to improve the universal acceptability of the technology in maritime ports. The study also explored the recent and significant developments in data privacy laws. The changes in the European Union and the U.S. significantly impact the block technology users. The jurisdictions in the data laws have always been approached differently, with the E.U. taking an omnibus approach while the U.S. is taking the patchwork. Harmonizing the E.U.'s GDPR draft and the EU E-privacy regulations creates an opportunity to improve compliance and operational efficiency in the blockchain technology application. The GDPR defines personal data to include the information that relates to an identity of a person (Balci and Surucu-Balci, 2021).

Blockchain technology presents significant potential in the maritime industry. The experiences with the Singapore maritime port show the technology's efficiency and operational sustainability. Singapore is located in a strategic location in the Malacia Strait and created an admirable harbor for maritime activities. In addition, the country has recorded significant developments in building advanced digital blockchain ships since 2019. The tremendous efforts adopted by Singapore in improving maritime operations make it one of the relevant case studies to explore in this study. The journey toward adopting blockchain technology in the marine industry has been marred with various challenges. The benefits and sustainable operations realized by a nation depends on the effectiveness of the efforts they put in place to address the issues (Liu and Wu, 2020).

The benefits of the Blockchain are tantalizing and would confer meaningful business growth opportunities. However, it may be considered ignorance to fail to analyze the existing challenges and how some of the ports globally have managed to address the issues. The study by Zhou et al. reported that international and government supports are essential for implementing block technologies in the ports. The study indicated that without such support, companies might need to be prepared to incur risks; this could further discourage the adoption of blockchain technology. The study indicated that the technology is meant to carry out transactions in encrypted blocks and could bring safety and trust to the parties involved. There ought not to be any weakness in terms of the features of the technology and its capability. An improvement in the security features will indicate that many companies will be able to adopt the technology. The study also highlighted the concept of accessibility as an essential success factor for blockchain utilization in Singapore. Cultivating a blockchain ecosystem is necessary for the practical, successful implementation of the technology (Zhou et al., 2020).

The adoption of blockchain technology in the maritime industry is still in its early stages and is subject to significant legal problems. There are currently no universal definitions and agreements on how blockchain technology in the shipping industry ought to operate. Significantly, blockchains do not need to be recorded publicly, which could result in enormous problems with the legal systems. Also, concerns with regulatory oversight remain a significant bottleneck to the adoption of blockchain technology, as indicated in the literature review. Such concerns can also be directly linked to the conflict with privacy laws. The E.U. introduced stricter laws in 2018 that clearly show that the blockchain architecture was not compliant with the GDPR. The study by Kaal et al. indicated the importance of having a blockchain governance model consistent with the GDPR. Currently, most blockchain technologies are not compliant with the regulation, which suggests that the issue could be addressed by having a GDPR privacy-by-design and privacy-by-default principle in the Blockchain. Addressing the regulatory issues will help increase technology use and improve the maritime industry experience. The study also indicated that the arising disputes ought to be solved using the smart contract as a separate layer that connects the users with the jurors through an online dispute resolution mechanism (Kaal et al., 2018).

Ports play an essential role in the maritime industry. The vessels must always obtain the port clearance certificate before departure or arrival. Getting a port clearance may require an

interaction of various entities. Conventionally, such processes would be achieved through manual paperwork, which was time-consuming. Blockchain technology is indisputable in enhancing the operations at the ports. The study reported that blockchain technology could be analyzed from the perspective of nodes forming the networks, the nodes keeping the replica of data, and the database constructed in chain forms. The study reports significant progress linked with blockchain technology's fundamental principle. The system was immune to a single-node attack, which means that a single attack would not affect the operation of the network. Similarly, immutable information indicates that no one can alter information integrity. Changing the data in the block would need modifying the pieces of information already in the chain, which would mean limiting all the blocks. The hash protects the data stored in blockchain technology (Panos et al., 2020).

Blockchain technology creates an opportunity where permissions can be limited to either public or private. The general system permits people to join the blockchain nodes, while the private ones are restricted to individuals with authorization only. The study also indicated that the issues arising from the bill of the landing were addressed using the CargoX dApp, allowing the customers to interact through the smart B.L. digital documents. Alternatively, the study also proposed the use of the essDocs Voltron that would facilitate paperless transactions. The technology can be integrated into the Blockchain to provide multi-bank channels that allow companies to manage the issuance of Letters of Credit and present the trade documents electronically (Panos et al., 2020).

Significant progress has already been made in the legal framework and regulations regarding integrating blockchain technology in the shipping industry. Arizona and Tennessee have enacted a law indicating that all blockchain signatures are electronic. In addition, blockchain technology provides an electronic record of transactions. The future laws indicated that the courts might not deny the contract legal validity considering that they are a smart contract. In addition, other nations are also trying to adapt to commercial laws and blockchain technologies. For example, Wyoming broke the ground by addressing the impacts of blockchain technology on the priority role of Article 9 of the Uniform Commercial Code. Also, Delaware and Maryland amended the General Corporation and limited liability company regulations to create more room for the use of blockchain technology. The legal frameworks have more significant implications for using blockchain technology in the shipping industry (Powell, 2021).

Parties are expected to supply agreements needed to decide whether the transactions can occur through the Blockchain. Flexibility is critical in the evolution of blockchain technology and its integration into the maritime industry. Tai analyzed the concept of the smart contract widely and its implication in blockchain technology. The study indicated that smart contracts are exciting developments that allow for the obligation's automatic performance. Also, such contracts do not require human intervention and are thus ideal for blockchain technology (Tai, 2019).

The computers linked to blockchain technology can execute complex programs and instructions, making it easy to adapt to as far as the transactions are concerned. The most popular innovative contract system is Ethereum. Using the contract requires the user to propose a contract and make it available in the blockchain system. The contract must have an identification number and exists as an autonomous entity within the system. Also, the users have to accept the contract through communication. The communication between the parties involved in the contract is evidence that the two parties were engaged. It becomes easy to follow the contract's terms and conditions in case of a dispute. The smart contract developments will address many issues hindering blockchain technology's use in the maritime industry. The most important thing is that the blockchain network environment allows smart contracts. Tai asserted that the contracts ought to facilitate the reception of signals from the outside world, meaning they must be christened oracles. The oracles can also connect to human beings who act as trusted third parties in the transactions. A good example involves a scenario where the courier signals that the goods were delivered to a port. This smart contract system can retrieve information about the state and packages as indicated by the sender. The oracles can also offer complex services such as evaluating the condition of the goods and whether there are any damages (Tai, 2019).

7.1 Smart Contracts.

The review of the existing literature analyzed alongside the case study has indicated significant progress in addressing the issues. Also, the findings indicated that some concerns still have not been addressed and could take time to solve. Blockchain technology supports the solving of many inefficiencies in the operation of the ports in the shipping industry, and so it is recommended that they adopt the system. Furthermore, the studies provide a global

implementation framework that may help maximize the desired outcomes while limiting the identified inefficiencies. One of the most important recommendations is the adoption of the smart contract, which will address the legal issues associated with the transactions conducted in the blockchain network. The findings in this study reported that the smart contract could be used at critical points along the shipment to ensure that all the essential data about the goods being transported are captured accordingly. The smart contract offers practical solutions and promises blockchain technology's application in the maritime industry. The successful integration of the smart contract in the blockchain network will reduce the incidences of claims emerging due to non-compliant by either of the parties in the trade agreement. The concept of smartness is appealing, considering that all the transactions will be automated and validation can also be done on time. The developments present significant financial benefits. In addition, there is a consensual agreement from the studies reviewed that smart contracts can facilitate collaborative interaction and improve the experiences of the parties involved in the shipping of goods. Equally, the technology is most likely to enhance the adoption of blockchain technology in the maritime industry. Blockchain technology in maritime operations aims to improve efficiency and minimize operating costs. The high cost involved in implementing the blockchain technology and the smart contract could make many ports shy from adopting the system (Jugović et al., 2019).

On the other hand, such ports may continue to suffer high operational costs resulting from the many intermediaries and the paperwork's cumbersome and time-consuming. The transition from paperwork to smart contracts culminates in a new logistic paradigm that improves the flow of goods and data between the parties involved in the transaction. Therefore, smart technology and Blockchain are promising areas that should be incorporated into daily maritime operations, despite the few more resilient challenges (Jugović et al., 2019).

7.2 Security Features.

DDoS attacks were special denial of service attacks that would compromise the functioning of the blockchains. The attacks can be classified as either brute, flooding, or spoofing. Flooding attacks are the most common and could completely paralyze the system's operation. Such attacks require that proper mitigations are developed to prevent them from reaching the network. Unfortunately, it was reported that DDoS could not be blocked or prevented through software installations. The Cochain-SC process network scheme governed by the Blockchain

using the smart contracts and the SDN could be used to mitigate the DDoS, as evident in the case of Rotterdam Port and the Port of Valencia. Also, the Wismar SeaPort used the Ethereum smart contract-based schemes that would significantly benefit the mitigation of DDoS attacks. Also, it is possible that the source of the traffic to the system can be monitored and estimated using entropy calculations based on the Shannon-s information theory. The SDN allows the collection of all illegitimate IPs for attack detection and can improve the efficient operation of blockchain technology in the shipping industry (Vujičić et al., 2020).

Blockchain technology is a decentralized system that stores data and transactions through a peer-to-peer network. The technology involves the blocks that were cryptographically connected. Blockchain technology creates an environment where maritime ports can improve the number of transactions they have at a lower cost. As much as the initial cost is a primary concern for the shipping industry, the beneficial outcomes are significant. Furthermore, the blockchain environment creates a secure system where the parties involved in the transaction can share the data securely. Significant studies have indicated that blockchain technology offers enormous security features that can benefit and improve online transactions' credibility. The study by Durán et al. also indicated that transactions through blockchain technology could be carried out in a secure environment without any risks of loss and so improve the speed of transmission. The anonymity of the information can be managed through the validation of the networks where all the participants interact (Durán et al., 2021).

There is enough evidence to indicate that blockchain technology offers an enormous solution to the shipping industry. Kapnississ et al. also suggested that the technology had been used to reduce the time wasted handling containers. The technology also protects custom documents from falsification, thus improving transparency. Therefore, in terms of security, blockchain technology has more benefits than worries (Kapnissis et al., 2020).

Confidentiality is an essential consideration for financial transactions. Anonymization is a technical challenge with blockchain technology, considering that most data are stored in the popular blockchain system. Significant issues have been raised regarding confidentiality. However, the review of the case studies indicates that the data stored in the blockchain network can be controlled regarding who can access it and who cannot. Blockchain technology is a digital block with information on given transactional records. Technological advancement and cybercrime indicate that exposing confidential transaction information can

be dangerous and compromise the entire system's reliability. The records on the Blockchain are secured through cryptography with private keys assigned to act as an individual's digital signature. In case of any alteration in the record, the signature becomes invalid, which means that the peer network will be able to note that something wrong has happened. It is impossible to eliminate the possibilities of crime and fraud in any system. However, the goal of the improvement interventions through the system developments and policy measures is to ensure that such incidences are minimized and the loss suffered is reduced (Kapnissis et al., 2020).

The blockchain network can be designed to provide the required security features that can be adopted from the Port of Rotterdam and Hainan Free Trade Ports. Private blockchains can be designed according to the platforms where they have to be deployed. Also, while the Blockchain has inherent properties offering security features, the vulnerabilities in the infrastructure can still be manipulated by people with ill intentions. However, the design of the Blockchain for the shipping industry must be made to prevent everyone from accessing sensitive data. Also, it should deny illicit attempts to change the network data. Besides, the system must be designed to carefully guard the encryption keys using high-grade security standards that will never be misappropriated. The capabilities in the blockchain network will add security integrity and improve its adoption. The concept of blockchain technology and its application in maritime ports are complex and require significant considerations other than security features. It is essential to learn how the system can be integrated into an enterprise-ready blockchain platform to increase the development and governance of the operations undertaken by the various business entities (Gao et al., 2022).

Blockchain systems are prone to information islands and can result in trust issues. Therefore, smart systems are proposed to help take advantage of the Blockchain's decentralized and tamper-free system combined with role-based access in realizing the desired functions in the maritime industry. The findings in the study by Liu et al. supported the fact that the regulation of the nodes added to the Fabric-PSchain systems could be used to enhance the credibility and security of the data shared in the blockchain network (Liu et al.,2022).

7.3 Legal Issues in Blockchain Technology.

In terms of the legal framework, the findings from the study indicated the need to have a standard system of the legal framework that will be used to address issues that arises with the use of blockchain technology. Maritime ports using blockchain technology are prone to various legal challenges that could arise from time to time. The smart contract offers effective solutions to disputes likely to arise in shipping ports that have already embraced blockchain technology. The smart contract captures detailed information about the container and terms of trade, making it easy to resolve the differences or failures in compliance with the obligations that may arise from time to time. Also, the IoT and sensors provide reliable solutions to issues associated with the legal framework limitations in blockchain technology. The essence of the legal framework is usually to create a system where parties can operate based on the stipulated agreements. Besides, a system must capture evidence to solve disputes likely to arise (McKinlay et al.,2022).

7.4 Environmental Concerns.

On the other hand, while blockchain technology offers many solutions to the shipping industry, the concerns about high energy consumption remain unsolved. The increased energy consumption could result in the accumulation of greenhouse gases and an increase in the carbon footprint, which could threaten long-term environmental conservation measures. Blockchain technology requires high computing power with a proof-of-work consensus system that consumes a lot of energy. The amount of energy consumed tends to increase with the complexity of the blockchain network. Other than the high energy used in the blockchain network, there are no other avenues linked with environmental degradation in technological adoption. Though, this area would require further research to explore how clean energy can be integrated to generate enough energy to facilitate the operation of the complex blockchain technology without compromising the environmental outcomes. The need for environmental conservation is an emerging concern emphasized by various global organizations to address the global warming phenomenon and the associated adverse outcomes. The current study

recommends that significant discourse should be directed at exploring better energy sources for the operation of blockchain technology in maritime ports (Liu et al.,2022).

7.5 Energy Consumption.

According to Philipp, seaports are the backbone of the transport network. The International Maritime Organization issues directives on reducing carbon into the environment following the long-term clean shipping strategy. Some of the policies developed included the Sulphur Emission Control Areas enacted in the IMO MARPOL Annex 2. Furthermore, a global Sulphur cap was introduced. Various nations have agreed to the call to reduce the number of greenhouse gases released into the environment. Such strategies have increased the interest of many ports to adopt digitalization operation approaches. Therefore, the promise presented by blockchain technology can leverage by reducing the other sources of pollution in the shipping industry. Regulating the pollution emitted from shipping fuels can help realize green energy. There are concerns linked to the high energy consumption in blockchain technology. There are opportunities for using alternative and green energy sources to generate power for the technology and minimize carbon and greenhouse gas emissions. The scope of implementing blockchain technology in the maritime industry requires a consideration of many factors brought together to achieve a cost-effective scenario. The world is undergoing a rapid revolution in the energy sector following the need to reduce greenhouse gas emissions. The initiative requires proactive steps from various, so the shipping industry should be at the forefront (Philipp, 2020).

7.6 Adaptability in Blockchain Technology in Maritime Ports.

The advent of blockchain technology has various implications for the adaptability to the existing systems. The scope focuses on analyzing how the technology can be integrated into the current systems. One of the outstanding concerns with using blockchain technology in maritime ports is the high installation and implementation costs. On the other hand, the development presents a more significant opportunity for improving the quality of service delivery in the industry and reducing the costs incurred in the long run. Blockchain technology allows users to store data on various devices worldwide. However, the participating entities must develop trust and appropriate participation in the network system.

The study by Kapnissis et al. proposed measures that the maritime industry players could take to improve the experiences and adaptability aspects of blockchain technology. The study described how distributed ledger technology could bridge the gap and improve the transition from paper to a digital bill of lading in the maritime industry. The study also highlighted the processes that must be undertaken to have a successful transaction. The study reported the need to have a conclusive receipt and the acknowledgment of the goods, the evidence of the terms of the contract of the carriage, and the document serving the title of the goods. Furthermore, the bill of lading must have additional features that allow the transferable of the papers of titles to the person who will be transferring the right of acquisition or reception of the goods (Kapnissis et al., 2020).

Also, there were indications that the limitation in adopting blockchain technology would be based on the inability to replace the existing practices that allow much flexibility. Besides, there are instances where the traders may not prefer their records to be registered in the central registry or cases where the buyers may not be interested in acquiring the bill of lading from the registry. There are instances where the liability of the e-bill of lading might not have been established, leading to expensive insurance contracts for the operations in the registry. It is essential that the contracting parties have the e-bill of lading and assess their ability to comply with the terms stipulated. In most cases, the transactions must be financed by a letter of credit, as indicated in the case of the Wismar Seaport (Kapnissis et al., 2020).

7.7 Suggestion for further research.

Although the research presents helpful insights into the challenges and for the correct implementation of Blockchain technology in the maritime port industry, additional research is necessary in several areas. Initially, it would be beneficial to conduct a more in-depth analysis of the regulatory framework and legal structures involving the implementation of Blockchain technology in ports. This would result in a more significant comprehension of the legal effects of the technology and the steps necessary to overcome any legal obstacles to implementation.

Furthermore, additional research could examine Blockchain technology's potential to improve supply chain management in the maritime port industry. This may involve an

investigation into the use of smart contracts and other Blockchain-based solutions to enhance the efficacy and transparency of supply chain operations.

To conclude, an ongoing investigation could be conducted to investigate the long-term effects of Blockchain technology on the maritime port industry. This would provide insight into the technology's sustainability, scalability, and ability to develop new business models and disrupt conventional supply chain practices. As a whole, these research areas could contribute to a deeper comprehension of Blockchain technology's potential to transform ports around the world.

References.

AFERM. n.d. *Understanding the Risk of "Immutable" Blockchain Applications*. [online] Available at: <https://www.aferm.org/erm_feed/understanding-the-risk-of-immutable-blockchain-applications/#:~:text=The%20inability%20to%20change%20information,substitute%20for%20stat

Afreen, S., 2022. *Why is Blockchain Important and Why Does it Matters*. [online] simplilearn.com. Available at: <https://www.simplilearn.com/tutorials/blockchain-tutorial/why-is-blockchain-important>.

Alahmadi, D., Baothman, F., Alrajhi, M., Alshahrani, F. and Albalawi, H., 2021. Comparative analysis of blockchain technology to support digital transformation in ports and shipping. *Journal of Intelligent Systems*, [online] Available at: <https://www.degruyter.com/document/doi/10.1515/jisys-2021-0131/html>.

Aramonte, S., Huang, W. and Schrimpf, A., 2021. *DeFi risks and the decentralisation illusion*. [online] Bis.org. Available at: <https://www.bis.org/publ/qtrpdf/r_qt2112b.htm>.

Arcelus, A., Yenikomshian, M. and Nocera, N., 2021. *Mitigating Antitrust Concerns When Competitors Share Data Using Blockchain Technology*. [online] Harvard Journal of Law & Technology. Available at: <https://jolt.law.harvard.edu/digest/mitigating-antitrust-concerns-when-competitors-share-data-using-blockchain-technology>.

Balci, G. and Surucu-Balci, E. (2021) *Blockchain adoption in the maritime supply chain: Examining barriers and salient stakeholders in containerized international trade*, 156, pp. 1–15.

Barberi, S., Sambito, M., Neduzha, L. and Severino, A., 2021. Pollutant Emissions in Ports: A Comprehensive Review. *Infrastructures*, [online] 6(8), p.9. Available at: <http://file:///Users/demo/Downloads/infrastructures-06-00114-v2.pdf>.

Bavassano, G., Ferrari, C. and Tei, A. (2020) "Blockchain: How Shipping Industry is dealing with the ultimate technological leap," *Research in Transportation Business & Management*, 34. Available at: https://doi.org/10.1016/j.rtbm.2020.100428.

Bechtsis, D. *et al.* (2019) "A blockchain framework for containerized food supply chains," *Computer Aided Chemical Engineering*, 46, pp. 1369–1374. Available at: https://doi.org/10.1016/b978-0-12-818634-3.50229-0.

Behnke, R., 2021. *HOW BLOCKCHAIN DDOS ATTACKS WORK*. [online] Halborn.com. Available at: <https://halborn.com/how-blockchain-ddos-attacks-work/>.

Biswas, D., Jalali, H., Ansaripoor, A. and De Giovanni, P., 2022. Traceability vs. sustainability in supply chains: The implications of blockchain. *European Journal of Operational Research*, [online] 304(2). Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0377221722004076>.

Blockchain smart port case: container release in the port of Antwerp (2021) *i - scoop*. i - scoop. Available at: https://www.i-scoop.eu/blockchain-smart-port-project-case-container-release-port-antwerp/.

Cargox.io. 2018. *A day to remember: The first ever blockchain-based CargoX Smart B/L™ has successfully completed its historic mission during a trial shipment from China to Europe*. [online] Available at: <https://cargox.io/press-releases/full/first-ever-blockchain-based-cargox-smart-bl-has-successfully-completed-its-historic-mission/>.

Casper, R., Ellis, N., Gehl, K., Haas, E., Lanza, J., Millendorf, S., Miller, V., Tantlef, A., Vogel, P., Wang, E. and Wegrzyn, K., 2021. *Legal Implications of Blockchain in Supply Chain: What's Law Got to Do With It? | Foley & Lardner LLP*. [online] Foley.com. Available at: <https://www.foley.com/en/insights/publications/2021/10/legal-implications-of-blockchain-in-supply-chain>.

CFI Team, 2021. *Smart Contracts*. [online] Corporate Finance Institute. Available at: <https://corporatefinanceinstitute.com/resources/knowledge/deals/smart-contracts/>.

Chang, Y., Iakovou, E. and Shi, W. (2019) "Blockchain in global supply chains and cross border trade: A critical synthesis of the state-of-the-art, challenges and opportunities," *International Journal of Production Research*, 58(7), pp. 2082–2099. Available at: https://doi.org/10.1080/00207543.2019.1651946.

Chaudhary, M. (2022) *Top 10 benefits of blockchain for businesses , Turing*. Turing

Enterprises Inc. Available at: https://www.turing.com/resources/blockchain-for-business.
Cloudflare.com. n.d. *What is a cryptographic key?*. [online] Available at: <https://www.cloudflare.com/en-gb/learning/ssl/what-is-a-cryptographic-key/>.

CMA CGM. 2022. *Press Release CMA CGM implements T-Mining's Secure Container Release blockchain solution in the Port of Antwerp*. [online] Available at: <https://www.cma-cgm.com/local/belgium/news/846/press-release-cma-cgm-implements-t-mining-s-secure-container-release-blockchain-solution-in-the-port-of-antwerp>.
cnbctv18.com. 2022. *Explained: Mempools and their importance in the Bitcoin mining process*. [online] Available at: <https://www.cnbctv18.com/cryptocurrency/bitcoin-mining-process-and-what-is-the-importance-of-mempools-explained-13961402.htm>.

Container xChange. 2022. *Blockchain shipping: What is it and why is it important?*. [online] Available at: <https://www.container-xchange.com/blog/blockchain-shipping/>.

DAC.digital. 2021. *Blockchain potential in the Maritime industry*. [online] Available at: <https://dac.digital/blockchain-potential-in-the-maritime-industry/>.
de Best, R., 2022. *Bitcoin average energy consumption per transaction compared to that of VISA as of April 25, 2022*. [image] Available at: <https://www.statista.com/statistics/881541/bitcoin-energy-consumption-transaction-comparison-visa/>.

DLA Piper. n.d. *BLOCKCHAIN: BACKGROUND, CHALLENGES, AND LEGAL ISSUES*. [online] Available at: <https://www.dlapiper.com/en/uk/insights/publications/2017/06/blockchain-background-challenges-legal-issues/>.

Donnelly, J., 2021. *Port of Rotterdam furthers cybersecurity efforts with new programme*. [online] Port Technology International. Available at: <https://www.porttechnology.org/news/port-of-rotterdam-furthers-cybersecurity-efforts-with-new-programme/>.

Donnelly, J., 2021. *Port of Rotterdam introduces Quay Connect blockchain technology*. [online] Port Technology International. Available at:

<https://www.porttechnology.org/news/port-of-rotterdam-introduces-quay-connect-blockchain-technology/>.

Dundar, A.O. and Kanduza, B.S. (2022) “THE EFFECTS OF BLOCKCHAIN TECHNOLOGY ON LOGISTICS INDUSTRY,” *BLOCKCHAIN IN FINANCE, MARKETING AND OTHERS* , p. 163.

Espelita, J., 2021. *TRUSTING A TRUSTLESS NETWORK. The Paradoxes of Trust in Blockchain Technology*. POSTGRADUATE MASTER’S DEGREE IN ECONOMIC AND POLITICAL SCIENCES. ISTITUTO UNIVERSITARIO SOPHIA LAUREA MAGISTRALE IN SCIENZE ECONOMICHE E POLITICHE.

Fenwick, M., Kaal, W.A. and Vermeulen, E.P.M. (2018) “Why 'blockchain' will disrupt corporate organizations,” *The Journal of British Blockchain Association* [Preprint]. Available at: https://doi.org/10.2139/ssrn.3227933.

Frankenfield, J., 2022. *Proof-of-Stake (PoS)*. [online] Investopedia. Available at: <https://www.investopedia.com/terms/p/proof-stake-pos.asp#:~:text=Proof%2Dof%2Dstake%20is%20a,and%20keeping%20the%20database%20secure.>.

Frankenfield, J., 2022. *What Is Double-Spending in a Blockchain?*. [online] Investopedia. Available at: <https://www.investopedia.com/terms/d/doublespending.asp#:~:text=Double%2Dspending%2

Gao, N. *et al.* (2022) “Modeling and analysis of Port Supply Chain system based on Fabric blockchain,” *Computers & Industrial Engineering* , 172. Available at: https://doi.org/10.1016/j.cie.2022.108527.

Gardner, N., n.d. *How can blockchain technology be applied to maritime law?*. [online] Thetius. Available at: <https://thetius.com/how-can-blockchain-technology-be-applied-to-maritime-law/>.

GeeksforGeeks. 2022. *Life Cycle of Smart Contract*. [online] Available at: <https://www.geeksforgeeks.org/life-cycle-of-smart-contract/>.

Gemini. 2020. *Double-Spend Attacks Examined: Past, Present, and Future*. [online] Available at: <https://www.gemini.com/cryptopedia/double-spend-attacks-bitcoin>.

Geroni, D., 2022. *Hybrid Blockchain: The Best of Both Worlds*. [online] 101Blockchains.com. Available at: <https://101blockchains.com/hybrid-blockchain/>.

Green, E., Carr, E., Winebrake, J. and Corbett, J., 2020. *Blockchain Technology and Maritime Shipping: An Exploration of Use Cases in the U.S. Maritime Transportation Sector*. [online] U.S. Maritime Administration, pp.43-44. Available at: <https://www.maritime.dot.gov/sites/marad.dot.gov/files/2020-07/Blockchain%20Use%20Cases%20Final%20Report%20%2820200622%29.pdf>.

Green, E., Carr, E., Winebreak, J. and Corbett, J., 2020. *Blockchain Technology and Maritime Shipping: An Exploration of Use Cases in the U.S. Maritime Transportation Sector*. [online] Available at: <https://www.maritime.dot.gov/sites/marad.dot.gov/files/2020-07/Blockchain%20Use%20Cases%20Final%20Report%20%2820200622%29.pdf>.

Groopman, J., n.d. *Top blockchain security attacks, hacks and issues*. [online] TechTarget.com. Available at: <https://www.techtarget.com/searchsecurity/tip/Top-blockchain-security-attacks-hacks-and-issues>.

Hackius, N., Reimers, S. and Kersten, W. (2019) "The privacy barrier for Blockchain in logistics: First lessons from the Port of Hamburg," *Logistics Management*, pp. 45–61. Available at: https://doi.org/10.1007/978-3-030-29821-0_4.

Hayes, A., 2022. *Blockchain Explained*. [online] Investopedia. Available at: <https://www.investopedia.com/terms/b/blockchain.asp>.

Hilary, G., 2018. *Blockchain: Security and Confidentiality.*. Georgetown University - McDonough School of Business.

Horizen Academy. n.d. *Attacks on Blockchain*. [online] Available at: <https://www.horizen.io/blockchain-academy/technology/advanced/attacks-on-blockchain/>.

IBM. n.d. *TradeLens Solution Brief*. [online] Available at: <https://www.ibm.com/account/reg/uk-en/signup?formid=urx-42717>.

Iredale, G., 2020. *Top Disadvantages of Blockchain Technology*. [online] 101 Blockchains. Available at: <https://101blockchains.com/disadvantages-of-blockchain/>.

Iredale, G., 2021. *Why Blockchain is Important in 2022 and Beyond*. [online] 101 Blockchains. Available at: <https://101blockchains.com/why-blockchain-is-important/>.

Jasper, K.-A. (2018) *Valenciaport joins TradeLens supply chain blockchain, Ledger Insight - blockchain for enterprise*. Available at: https://www.ledgerinsights.com/valencia-port-tradelens-supply-chain-blockchain/.

Jaswant, S.S. and Kale, P. (2021) "Smart contracts and blockchain: Legal issues and implications for Indian Contract Law," *International Review of Law, Computers & Technology*, 36(3), pp. 1–18. Available at: https://doi.org/10.1080/13600869.2021.1999312.

Jeacocke, S. and Kouwenhoven, N., n.d. *TradeLens uses blockchain to help Customs authorities facilitate trade and increase compliance*. [online] WCO News. Available at: <https://mag.wcoomd.org/magazine/wco-news-87/tradelens/>.

Kapnissis, G., Vaggelas, G., Leligou, H., Panos, A. and Doumi, M., 2022. Blockchain adoption from the Shipping industry: An empirical study. *Maritime Transport Research*, [online] 3(100058). Available at: <https://www.sciencedirect.com/science/article/pii/S2666822X22000090>.

Katrenko, A. and S, M., 2020. *Blockchain Attack Vectors: Vulnerabilities of the Most Secure TechnologyIt was originally published on https://www.apriorit.com/*. [online] apriorit.com. Available at: <https://www.apriorit.com/dev-blog/578-blockchain-attack-vectors>.

Kern, P., 2021. *Electronic bill of lading #eBL*. [online] Cargox.io. Available at: <https://cargox.io/blog/electronic-bill-lading-ebl/#:~:text=A%20blockchain%20bill%20of%20lading,unbreakable%20confidentiality%20among%2

Krishna, A., 2022. *Blockchain Security Issues - A Complete Guide*. [online] Getastra.com. Available at: <https://www.getastra.com/blog/knowledge-base/blockchain-security-issues/>.

Lasmoles, O. and T. Diallo, M. (2022) "Impacts of blockchains on International Maritime Trade," *Journal of Innovation Economics & Management*, N° 37(1), pp. 91–116. Available at: https://doi.org/10.3917/jie.pr1.0114.

Lasmoles, O. and T. Diallo, M., 2022. Impacts of Blockchains on International Maritime Trade. *Journal of Innovation Economics & Management*, N° 37(1), pp.91-116.

Liu, C. and Wu, S. (2020) "The application of blockchain to Intelligent Port Logistics—— Taking Hainan Free Trade Port as an example," *Journal of Physics: Conference Series*, 1624(3). Available at: https://doi.org/10.1088/1742-6596/1624/3/032053.

Liu, Y. *et al.* (2022) *Verifying the smart contracts of the port supply chain system based on probabilistic model checking*, *MDPI*. Business Model–the Perspective of Systems Thinking and Innovation. Available at: https://www.mdpi.com/2079-8954/10/1/19.

Lofvers, M., 2022. *Belgian and Dutch ports are putting blockchain into practice*. [online] Supply Chain Movement. Available at: <https://www.supplychainmovement.com/belgian-and-dutch-ports-are-putting-blockchain-into-practice/>.

Marineinsight.com. 2019. *7 Major Blockchain Technology Developments In Maritime Industry*. [online] Available at: <https://www.marineinsight.com/know-more/7-major-blockchain-technology-developments-in-maritime-industry-in-2018/>.

Mathews, V. and Bhowmik, N., 2022. *Chaining Intellectual Property Rights To Blockchain*. [online] BW bwlegalworld. Available at: <http://bwlegalworld.businessworld.in/article/Chaining-Intellectual-Property-Rights-To-Blockchain/17-05-2022-428409/>.

Mathur, V., 2022. *What is a Consortium Blockchain?*. [online] Analyticssteps.com. Available at: <https://www.analyticssteps.com/blogs/what-consortium-blockchain>.

McKinlay, J. *et al.* (2018) *Blockchain background challenges legal issues*, *DLA Piper*. Available at: https://www.dlapiper.com/en/insights/publications/2017/06/blockchain-background-challenges-legal-issues.

Mitra, M., 2019. *6 Challenges of Blockchain*. [online] Mantralabsglobal.com. Available at: <https://www.mantralabsglobal.com/blog/challenges-of-blockchain/>.

Napoleatano, E. and Broverman, A., 2022. *Proof of Work Explained*. [online] Forbes. Available at: <https://www.forbes.com/advisor/ca/investing/cryptocurrency/proof-of-work/#:~:text=Proof%20of%20work%20is%20a,the%20integrity%20of%20new%20data.>.

Nibley, B., 2022. *Proof of Stake: A process used to validate crypto transactions through staking*. [online] Business Insider. Available at: <https://www.businessinsider.com/personal-finance/proof-of-stake?international=true&r=US&IR=T>.

Obafemi, F., 2022. *Blockchain Applications in Business: Cost Implications*. [online] flexiple.com. Available at: <https://flexiple.com/blockchain/blockchain-applications-in-business-cost-implications/>.

Oxford Reference. n.d. *metadata*. [online] Available at: <https://www.oxfordreference.com/view/10.1093/acref/9780199571444.001.0001/acref-9780199571444-e-2097>.

Panos, A., Kapnissis, G. and Leligou, H. (2020) "Blockchain and DLTs in the Maritime Industry: Potential and Barriers," *European Journal of Electrical Engineering and Computer Science*, 4(5). Available at: https://doi.org/10.24018/ejece.2020.4.5.243.

Parizo, C., 2021. *4 main types of blockchain technology*. [image] Available at: <https://www.techtarget.com/searchcio/feature/What-are-the-4-different-types-of-blockchain-technology>.

Parizo, C., 2021. *What are the 4 different types of blockchain technology?*. [online] SearchCIO. Available at: <https://www.techtarget.com/searchcio/feature/What-are-the-4-different-types-of-blockchain-technology>.

Perkušić, M., Jozipović, Š. and Piplica, D. (2020) "Need for legal regulation of Blockchain and smart contracts in the shipping industry," *Transactions on Maritime Science*, 9(2), pp. 365-373. Available at: https://doi.org/10.7225/toms.v09.n02.019.

Philipp, R., Prause, G. and Gerlitz, L. (2019) "Blockchain and smart contracts for entrepreneurial collaboration in maritime supply chains," *Transport and Telecommunication Journal*, 20(4), pp. 365–378. Available at: https://doi.org/10.2478/ttj-2019-0030.

Pike, C. and Capobianco, A., 2020. *Antitrust and the trust machine*. [online] Oecd.org. Available at: <https://www.oecd.org/daf/competition/antitrust-and-the-trust-machine-2020.pdf>.

Planetcompliance.com. n.d. *Blockchain in Financial Services - Compliance and Regulatory Challenges*. [online] Available at: <https://www.planetcompliance.com/blockchain-financial-services-compliance-regulatory-challenges/>.

Port of Hamburg. 2021. *DAKOSY and dbh digitalize the release process for German Ports*. [online] Available at: <https://www.hafen-hamburg.de/en/press/news/dakosy-and-dbh-digitalize-the-release-process-for-german-ports/?>.

Port of thessaloniki adopts blockchain technology with TradeLens (2021) *Port Technology International*. Port Technology International. Available at: https://www.porttechnology.org/news/port-of-thessaloniki-adopts-blockchain-technology-with-tradelens/.

PortXchange. n.d. *Digital solutions for predictable and sustainable shipping*. [online] Available at: <https://port-xchange.com/?utm_term=port%20xchange&utm_campaign=Search-Branded+Keywords&utm_source=adwords&utm_medium=ppc&hsa_acc=7423795809&hsa_cam=10508310913&hsa_grp=102656833623&hsa_ad=475812112072&hsa_src=g&hsa_tgt=kwd-926494120221&hsa_kw=port%20xchange&hsa_mt=e&hsa_net=adwords&hsa_ver=3&gclid=Cj0K

PortXchange. n.d. *Our Story*. [online] Available at: <https://port-xchange.com/about-portxchange/>.

Powell, N.M. (2021) "Delaware Harmonizes Alternative Entity Series and UCC Article 9," *The Business Lawyer*, 76, pp. 1141–1155. Available at: https://www.youngconaway.com/content/uploads/2021/11/001-TBL-76-4-Powell-.pdf.

Ppiaf.org. n.d. *Alternative Port Management Structures and Ownership Models*. [online] Available at: <https://ppiaf.org/sites/ppiaf.org/files/documents/toolkits/Portoolkit/Toolkit/module3/port_fu

Pratt, M., 2021. *Top 10 Benefits of Blockchain Technology for Business*. [online] techtarget.com. Available at: <https://www.techtarget.com/searchcio/feature/Top-10-benefits-of-blockchain-technology-for-business>.

Richardson, B., 2017. *The Port's Real Estate: Big Leases, Big Money*. [online] lbbusinessjournal. Available at: <https://lbbusinessjournal.com/real-estate/the-port-s-real-estate-big-leases-big-money>.

Rodrigue, J., 2020. *The Geography of Transport Systems*. 5th ed. Routledge, pp.Chapter 6.3.

Schneier, B., 2019. *There's No Good Reason to Trust Blockchain Technology*. [online] WIRED. Available at: <https://www.wired.com/story/theres-no-good-reason-to-trust-blockchain-technology/>.

Seth, S., 2022. *Public, Private, Permissioned Blockchains Compared*. [online] Investopedia.com. Available at: <https://www.investopedia.com/news/public-private-permissioned-blockchains-compared/>.

Shuaib, M., Alam, S., Ahmed, R., Nasir, M., Alam, M. and Qamar, S., 2022. *Current Status, Requirements, and Challenges of Blockchain Application in Land Registry Journal Article | IGI Global*. [online] Igi-global.com. Available at: <https://www.igi-global.com/gateway/article/full-text-html/299934&riu=true>.

Sillaber, C. and Waltl, B., 2017. *The life cycle of a smart contract: phases, actors, and services.*. [image] Available at: <http://Life Cycle of Smart Contracts in Blockchain Ecosystems>.

Singh, J., 2022. *The life cycle of smart contracts in the blockchain ecosystem*. [online] Cointelegraph. Available at: <https://cointelegraph.com/explained/the-life-cycle-of-smart-contracts-in-the-blockchain-ecosystem>.

Suripeddi, M. and Purandare, P., 2021. Blockchain and GDPR – A Study on Compatibility Issues of the Distributed Ledger Technology with GDPR Data Processing. *Journal of Physics: Conference Series*, [online] 1964(4), p.042005. Available at: <https://iopscience.iop.org/article/10.1088/1742-6596/1964/4/042005/pdf>.

T-Mining. n.d. *Building trusted collaboration*. [online] Available at: <https://t-mining.be/>.

Tai, E.T. (2019) "Challenges of smart contracts: Implementing excuses," *The Cambridge Handbook of Smart Contracts, Blockchain Technology and Digital Platforms*, pp. 80–101. Available at: https://doi.org/10.1017/9781108592239.005.

Takyar, A., n.d. *Cost of Blockchain Implementation: Process*. [image] Available at: <https://www.leewayhertz.com/cost-of-blockchain-implementation/>.

Technology Record. 2017. *Cybersecurity via blockchain: the pros and cons*. [online] Available at: <https://www.technologyrecord.com/Article/cybersecurity-via-blockchain-the-pros-and-cons-62035#:~:text=There's%20a%20risk%20that%20encrypted,key%20necessary%20to

Techopedia.com. n.d. *What Does Mining Mean?*. [online] Available at: <https://www.techopedia.com/definition/32530/mining-blockchain#:~:text=Techopedia%20Explains%20Mining-,What%20Does%20Mining%20Mean%3F,using%20the%20blockcahin%20employ%20mining.>.

Tradelens.com. n.d. *Accelerate your move to a fully digital port*. [online] Available at: <https://www.tradelens.com/network/ports-and-terminals>.

Tsiulin, S. *et al.* (2020) "Blockchain-based applications in shipping and Port Management: A literature review towards defining key conceptual frameworks," *Review of International Business and Strategy*, 30(2), pp. 201–224. Available at: https://doi.org/10.1108/ribs-04-2019-0051.

Tsiulin, S., Reinau, K., Hilmola, O., Goryaev, N. and Karam, A., 2020. Blockchain-based shipping and port management applications: a literature review towards defining key conceptual frameworks. *Review of International Business and Strategy*, [online] 30(2), pp.201-224. Available at: <https://www.researchgate.net/publication/341880037_Blockchain-

based_applications_in_shipping_and_port_management_a_literature_review_towards_defining_key_

Vereckey, B., 2022. *Decentralized finance: 4 challenges to consider*. [online] MIT Sloan. Available at: <https://mitsloan.mit.edu/ideas-made-to-matter/decentralized-finance-4-challenges-to-consider>.

Vitasek, K. *et al.* (2022) *How Walmart Canada Uses Blockchain to Solve Supply-Chain Challenges, Harvard Business Review*. Harvard Business Review. Available at: https://hbr.org/2022/01/how-walmart-canada-uses-blockchain-to-solve-supply-chain-challenges.

Vujičić, S. *et al.* (2020) "Distributed Ledger Technology as a tool for environmental sustainability in the shipping industry," *Journal of Marine Science and Engineering*, 8(5), p. 366. Available at: https://doi.org/10.3390/jmse8050366.

Walker, T. and Adams, M., 2021. *How shipping ports can become more sustainable*. [online] The Conversation. Available at: <https://theconversation.com/how-shipping-ports-can-become-more-sustainable-156483>.

Watts, A., 2022. *Future of Blockchain Is Reversible Transactions*. [online] Coincodex.com. Available at: <https://coincodex.com/article/16461/future-of-blockchain-is-reversible-transactions/>.

Wegrzyn, K. and Wang, E., 2021. *Types of Blockchain: Public, Private, or Something in Between*. [online] Foley.com. Available at: <https://www.foley.com/en/insights/publications/2021/08/types-of-blockchain-public-private-between>.

Whitfield, B., 2022. *What Is Blockchain Technology? How Does It Work? | Built In*. [online] Builtin.com. Available at: <https://builtin.com/blockchain>.

Xiu, C. and Li, T. (2022) *Construction of the Hainan Free Trade Port from the perspective of regional cultural development*, *Frontiers*. Frontiers. Available at: https://www.frontiersin.org/articles/10.3389/feart.2022.1032953/full.

Zarrin, J., Wen Phang, H., Babu Saheer, L. and Zarrin, B., 2021. *Blockchain for decentralization of internet: prospects, trends, and challenges*. [online] Springer. Available at: <https://link.springer.com/article/10.1007/s10586-021-03301-8>.

Zhou, Y. *et al.* (2020) "The key challenges and critical success factors of Blockchain Implementation: Policy Implications for Singapore's maritime industry," *Marine Policy*, 122. Available at: https://doi.org/10.1016/j.marpol.2020.104265.