Blockchain in Maritime Supply Chain: A Synthesis Analysis of Benefits, Challenges and Limitations

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Blockchain is a promising decentralized information technology that could benefit supply chains by increasing transaction transparency and efficiency, reducing cost and transaction time, as well as building trust and secure transactions among participants. In this paper, we discuss how blockchain could benefit the maritime supply chain. We explore specifically how blockchain technology provides solutions to challenges in the maritime industry, namely, reduction in paperwork and transaction time, enhanced transaction security, optimization in port operations, and sustainability promotion. We also discuss the challenges and limitations of blockchain adoption in the maritime supply chain.

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I. INTRODUCTION

Supply chain is a network of organizations, people, activities, and resources, which in one direction, move a product or service from supplier to customer, and in the other direction transfer information from customer to supplier. It comprises the entire product lifecycle before it reaches a customer. Supply chains were relatively simple before globalization came into picture. Since then, there have been innovations in each and every part of supply chains that have led to the complexity and difficulty in tracking products (Marr, 2018). There have been unethical practices and lack of transparency involved within various supply chains around the world. Counterfeit products have caused losses in market share and trust amongst supply chain members (Chen et al., 2017). Product recalls have damaged consumer trust and incurred huge unnecessary supply chain costs. Consumers have shown a need to validate a purchase, as

well as to track product and to have access to environmental impacts along the supply chain flow. The need for supply chain transparency, social responsibility and accountability has increased substantially in the past few years. There is also a need for business to business (B2B) integration within supply chains, referring to the electronic data exchanged over the internet between business partners and value-added service providers (Korpela et al., 2017). As a result, many companies have developed their own information technology systems, in order to efficiently track and manage their global supply chains. However, even the biggest organizations lack the power, knowledge or capability to themselves design or deploy end-to-end information integration through supply network. For that reason, companies have collaborated to accelerate integration under the concept of the digital supply chain. For example, some companies work with national and international financial institutions and regulatory agencies in order to provide more visibility and security.

Maritime supply chain is defined as the movement of cargoes and related support service involving two substantial locations using maritime and land transportations. Maritime transport is an essential link of the global trade and is estimated to be valued at $1.8 trillion annually. More than 90 percent of global trade is carried out by the shipping industry each year. Today, the maritime industry is facing many challenges. One of the major challenges in today's maritime supply chain is to efficiently and effectively integrate national and international ecosystems and participants. As interactions among maritime supply chain participants become more complex and dynamic, the supply chain efficiency suffers from the lack of transparency and flexibility in supply chain operations. This results in lengthened shipping time, worsened service levels, inefficient use of resources, and subsequently higher costs.

Blockchain, a new distributed information technology, can provide solutions to challenges in the maritime supply chain. Blockchain has been introduced as a new paradigm that can enhance the traceability of production and logistics activities. It is an alternative solution which reduces the role of intermediaries whose servers are vulnerable to crashes, frauds, and hacks (Tapscott and Tapscott, 2017). Consequently, it can increase the efficiency and transparency of supply chains and positively impact everything from warehousing to delivery to payment (Azzi et al., 2019). In essence, it provides a record of transactions which cannot be tampered or altered. All data (i.e., sales, shipping, design) collected through different parts of the supply chain needs to be validated before becoming a permanent record. The decentralization attribute of blockchain facilitates the secure distribution of data across the network as no single node alone can control the whole transaction.

In this paper, we attempt to answer the following research question: *how can blockchain technology help supply chain operations become more transparent, efficient and trustworthy in the maritime supply chain?* In order to address this research question, we first introduce the concepts and theories behind blockchain. We then discuss the benefits of blockchain for supply chain operations. We focus on our discussion of blockchain application in the maritime supply chain. The discussion on the business applications of blockchain highlights the benefits and the challenges to be taken into consideration in creating a blockchain-based supply chain (Eisenhardt, 1989).

The rest of the paper is structured as follows. In section 2, we review relevant literature regarding blockchain and its

application and status in supply chains. In section 3, we present the applications of blockchain in the maritime supply chain. We conclude the paper in section 4.

II. LITERATURE REVIEW

The blockchain technology was introduced along with Bitcoin by Satoshi Nakamoto (Nakamoto, 2008). Blockchain is a chain of blocks in a database, called "Distributed Shared Ledger", which is distributed amongst a given business network (Hastig and Sodhi, 2020). A block is a set of records that has a pointer to data in another block, creating a link in a chain of such relations. Blockchain is reliable and difficult to hack due to its shared, immutable ledger (Iansiti and Lakhani, 2017). Both tangible and intangible assets can be stored and traded with reduced risks and costs on a blockchain network.

As illustrated in Figure 1, transactions in a traditional ledger are processed through a central point. In a distributed shared ledger, transactions are processed by multiple nodes simultaneously, and data are shared, replicated and synchronized amongst the members of a decentralized network. What's more, participants can only see transactions that they are authorized to see (i.e., it is permissioned) (Brakeville and Perepa, 2019).

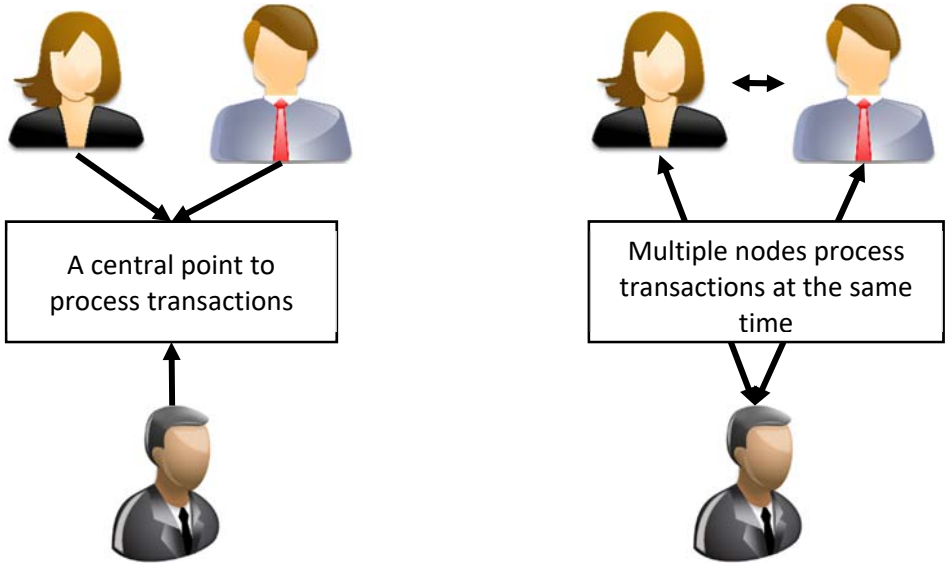

FIGURE 1. DISTRIBUTED SHARED LEDGER

Blockchain consists of blocks which store information on the business network. Each block consists of data, hash, and hash of the previous block. Data varies depending on the type of chain it is involved in. For example: For the Bitcoin, it includes information about the transaction such as sender, receiver, and bank. Hash provides a unique identity to the block. Once the data is determined, the calculation for the hash begins. Hash can be compared to a fingerprint, which is very difficult to tamper with. If tampered, the calculations inside the block changes and it can be easily detected. Thus, this makes the blockchain secure. Each block consists of hash of previous block to help link the blocks in the network. If one block is tampered, it would not be able to link

to other blocks, and the network would break. All the information presented in the block is based on a given consensus that is provided by the participants.

Many researches have been conducted on the future of blockchain in supply chain management. Babich and Hilary (2020) provide a comprehensive review of blockchain studies and the potential applications of blockchain in operations and supply chain management. Kshetri (2018) uses multiple case studies to investigate the impact of the blockchain on key objectives of supply chain management. Blockchain has also been proposed to manage the environmental impacts of supply chain such as carbon emission (Liu et al., 2019; Manupati et al., 2020). Saberi et al. (2019) explore the main barriers in adoption of blockchain to fulfill the goal of a sustainable supply chain.

In the past few years, blockchain has undergone intensive growth through various new innovative and technological concepts. However, blockchain is still in the initial stages of being fully utilized in supply chains. Many companies have indicated their interests in this new technology. DeCovny (2017) conducted a survey with 42 supply chain management professionals, including supply chain practitioners, shipping agents, and technology providers. The result shows that the participants are positive about the prospect of blockchain in supply chains. 42.5% of all participants have indicated they plan to implement blockchain within 1 year, 20% in two years, 5% within 5 years, whereas 30% do not have any plan and 2.5% will never implement it.

The possibilities of applying the blockchain technology have gained momentum in many supply chains (Helo and Hao, 2019), e.g., in notary services, central banks and other centralized trusted identity middlemen (Efanov and Roschin, 2018). Many companies have launched pilot projects all around the globe. For example, U.S. has recently used blockchain for government services (US General Services Administration, 2018). China has created a blockchain application subcommittee for regulating blockchain (Buxbaum, 2017). Albert Heijn, a supermarket in the Netherlands, has enabled the blockchain technology to track its orange juice from farms in Brazil to supermarket shelves (Southey, 2019).

However, many more companies are still observing the development of blockchain from a distance. Hackius and Petersen (2017) have recently conducted an online survey and asked 152 professionals in consulting, logistics services and sciences from Germany, United States, Switzerland and France for their opinion on blockchain adoption in logistics and supply chain management. They conclude that although the majority of participants recognize the benefits of blockchain, they do not have a consistent opinion over the likelihood of adoption. The results show that 43% of participants do not look into blockchain just yet, 37% are investigating blockchain use cases, and 20% have implemented first blockchain solutions.

We next discuss the applications of blockchain and its benefits and challenges in the maritime supply chain.

III. BLOCKCHAIN APPLICATIONS IN MARITIME SUPPLY CHAIN

In this section, we present the business applications of blockchain in the maritime supply chain to illustrate how blockchain benefits supply chains by increasing transaction transparency and efficiency, reducing costs and transaction time, as well as building secure transactions among participants. We also explore the challenges and limitations of blockchain in the maritime supply chain.

The maritime supply chain begins at shippers, followed by freight forwarders, terminal operators, ocean carriers, customs authorities, and port authorities, and reaches the final consumer (beneficial cargo owner) at the end. Different information is involved at every stage of the maritime supply chain, and all the information can be written to the blockchain, as described in details below:

- *Shippers*: Information of shipping instructions.
- *Freight Forwarders*: Information about transportation plan, inland events, intermodal handoffs and document fillings.
- *Terminal Operators*: Information about movement of cargo container between cargo ships, trucks and freight trains.
- *Ocean Carriers*: Information about the deposition of shipment at the ocean leg.
- *Customs Authorities*: Information about the customs clearance status of import and export from and within a country.
- *Port Authorities*: Information about the deposition of shipment at the boundaries.
- *Beneficial Cargo Owner:* In the blockchain network, beneficial cargo owner would be able to access information from an ocean carrier's or freight forwarder's online booking platform, and get automated shipment and port updates.

Figure 2 illustrates an example of blockchain in the maritime industry. It emphasizes that all the transaction data along the maritime supply chain becomes shared and immutable ledgers on a blockchain platform. It thus creates transparent, reliable, secure and tamper-resistance supply chain information that can be accessed by authorized supply chain members.

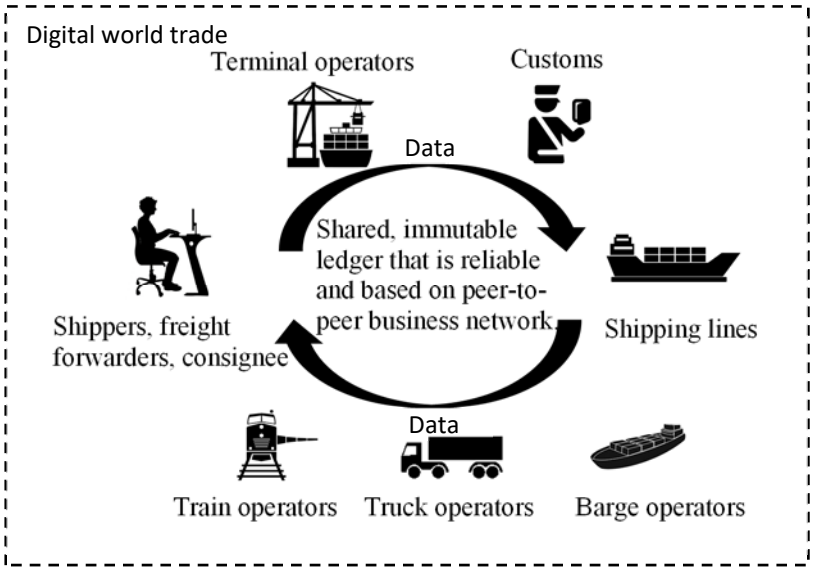

FIGURE 2. BLOCKCHAIN IN THE MARITIME INDUSTRY

3.1. Blockchain Solutions to Challenges in the Maritime Supply Chain

Blockchain can act as a great solution to transform and digitalize the maritime supply chain. A majority of the shipped goods in the maritime industry is slowed by the sheer shipping volume and its paperwork, and point-to-point communication. Blockchain provides a digital trade platform that provides businesses and authorities along

the supply chain with a single and secure source of shipping data. It enables digital collaboration across multiple parties involved in the trade. Shippers, freight forwarders, ocean carriers, port and terminal operators, inland transportation, customs and port authorities can interact more efficiently through real-time access to shipping data and shipping documents. The implementation of blockchain can improve shipping supply chain efficiency, load traceability, and communication efficiency (Ahuja et al., 2020).

Blockchain promises trust, secure and authenticated information exchange in supply chains (Dujak and Sajter, 2019). Blockchain can be implemented in different areas of supply chains including tracking product origin (traceability), product flow (visibility), demand forecasting, decreasing of fraud and counterfeit products, and transaction automation (Dujak and Sajter, 2019). Chang et al. (2020) state that the capabilities of blockchain can address many challenges in global supply chains.

A recent study conducted in Nhava Sheva, one of the largest ports in India, shows that blockchain could save about $860 million by digitizing the process with the help of TradeLens, a blockchain-based shipping platform by IBM. It helped importers and exporters save about $220 million and $40 million, respectively, by lowering transport and logistics costs with shorter lead time and fewer delays (Westergaard-Kabelmann, 2019).

Next, we illustrate the benefits of blockchain in the maritime supply chain, by looking into the major challenges in the maritime industry and how blockchain provides solutions for them.

(a) Reduction in paperwork and the associated cost

The burden of paperwork is one of the major challenges in the maritime industry. There are large amounts of documents to accompany maritime shipping transactions, including bills of lading, sales contracts, letters of credit, customs releases, commercial invoices, charter party contracts, port documents, etc. The processing and transaction of documents are very time-consuming and costly, because of the involvement of a large amount of different parties, and the traditional way of sharing documents via email attachment, fax and courier. According to Maersk, a single container could require stamps and approvals from as many as 30 people, including customs, tax officials and health authorities to be shipped from the port of origin to the port of destination (Popper and Lohr, 2017). The cost of the paperwork is estimated to be between 15 and 50 percent of the costs of physically moving the container around the world (Groenfeldt 2017; Popper and Lohr 2017).

Blockchain could eliminate or drastically reduce the paperwork, and revolutionize the way of data sharing in the maritime industry. Blockchain enables digitized documents, where users can easily view shared documents for a given consignment, easily identify new version of document, and guarantee immutability and traceability of trade documents. The encryption process of blockchain links every party, such as port and terminal operators, cargo owners, customs authorities, freight forwarders, brokers and transportation companies, in a seamless digital process (Pope, 2019). This eliminates the need of endless round of paper document checks and rechecks, and reduce the high costs associated in the manual and paper-based system.

Traditionally, shipping data is shared through the EDI (Electronic Data Interchange) systems, but these systems are inflexible, complex, and cannot share data in real-time (MI News Network, 2018b). Blockchain can

track critical data of every step of the shipment in the maritime supply chain and offers real-time and immutable data records among all parties involved. This would enable all parties to execute physical transactions, exchange and store sensitive information in an encrypted format. This would also allow a seamless delivery of contractual obligations, present and accept instructions and exchange payments in a secure manner (Pope, 2019).

The first ever bill of lading issued with the blockchain technology, CargoX Smart Bill of Lading™, has showcased the benefits of blockchain in reducing paperwork and the associated cost. Bill of lading is the legal document issued by a carrier to a shipper that details the type, quantity, and destination of the goods being carried. A bill of lading also serves as a shipment receipt when the carrier delivers the goods at a predetermined destination. Bill of lading is a very important document, since whoever holds the bill owns the cargo. Consequently, the transfer of bills from exporter to importer has long been critical. Traditionally, bill of lading are sent by couriers, incurring a significant cost and time. It may takes as long as the cargo to reach its intended recipients (Kukman, 2018). Sometimes, cargo arrives at port before the original bill of lading due to bank delays and other issues (Czachorowski et al., 2019). MI News Network (2018a) reported that, in August 2018, a container from Shanghai, China was released successfully in the Port of Koper, Slovenia. The bill of lading of this shipment was issued electronically and transferred in a blockchain network from shipper to consignee the first time ever in the maritime industry. The whole process took minutes with the help of blockchain, instead of the usual days or weeks. The cost of such a safe electronic bill of lading was at $15, which is a mere fraction, approximately 15% of the estimated usual price for a paper document to be transferred through international courier services. In addition, the chances of loss, theft or damage to the bill of lading have been drastically reduced to near-zero.

(b) Reduction in transaction time

Blockchain allows workflow automation, where automatic verification and execution of transactions can be initiated and conducted through smart-contracts when certain requirements are met (Christidis and Devetsikiotis, 2016). Data is automatically extracted from the packing lists and customer invoices in the broker's system, once shippers upload packing lists in the blockchain. The broker would be able to use this information to create a customs declaration form for a faster clearance process, once the vessel departs. This will reduce transaction time and prevent delays caused by documentation errors, information delays, and other impediments. What's more, the real-time information sharing character of blockchain enables easier accessibility for documents, quicker filings and faster payment. Consequently, blockchain adoption in the maritime supply chain could improve operational efficiency, prevent delays and reduce transaction time.

Many studies have demonstrated the effectiveness and efficiency of blockchain in reducing transaction times in the maritime industry. In one of the experiments conducted by Maersk and IBM, it has been shown that blockchain could reduce the transit time of a shipment of packaging materials to a production line in the United States by 40 percent and avoid thousands of dollars in cost (MI News Network, 2018b). In addition, blockchain offers better visibility and more efficient means of communicating. This could help reduce the steps taken to answer basic operational questions, such as "where is my container", from ten steps and five people to one step and one person (MI News Network, 2018b).

In the Nhava Sheva port case, blockchain helped reduce time on import documentation from 67 hours to 35 hours, and reduce import cost of transportation and logistics by 2 percent. The blockchain technology also helps reduce customs clearance delays in the port, since the required customs documents are available digitally on the shared ledger. Customs officer can easily access documents up to three weeks prior to ship arrival, as opposed to currently 2-3 days (Westergaard-Kabelmann, 2019).

(c) Enhanced transaction security

Blockchain provides a new method of real-time, secure, trustable, verifiable communication and information sharing to all parties in the maritime supply chain. The security of shipments can be protected by the traceability, transparency and immutability of blockchain. Blockchain network shares the safely encrypted documents and shipping data among all the owners and stakeholders of a shipment. Only authorized users can publish and access data involved in the shipping process. For example, when a block of data is created and encrypted, e.g., shipment details of a specific container, only parties involved in that transaction can have access to the data. Some blockchain platforms, such as IBM TradeLens, also provides permission access and control for shipping milestones. Blockchain immutability guarantees that the original shipping document cannot be altered. A new block of data will be created for any additions or changes of the original document, and will be linked to the original one. All versions of these documents are stored in the blockchain to guarantee their traceability and immutability. Transparency is also useful for checking whether a document transfer has been successful (Kukman, 2018). The blockchain network is transparent, immutable and open. It validates user accounts with hardware encrypted ledgers and ensures the security of all transactions.

Blockchain solution has been utilized to secure container-release operations in the Port of Antwerp, which is the second-largest seaport in Europe and a vital link for global trade. The blockchain solution creates digital rights to ensure that no unauthorized party can show up at the terminal to claim containers. All required information for container-release and transactions is securely and permanently stored in the blockchain, and only authorized parties have access to the information (Chang et al., 2020; Sluijs, 2017).

In the maritime industry, the originality of goods often relies on paper certificates that can get lost or tampered with (Lomas 2015). This challenge can be addressed by smart contract of blockchain, which automatically and securely initiates document/certificate flow between involved parties in real time. Smart contract also eliminates the chance of duplicating the certificates and guarantee their authenticity. The Port of Antwerp and T-Mining have successfully verified the efficiency of document flow with blockchain smart contract in a pilot project, where they studied the transportation of apples from New Zealand to Belgium with phytosanitary certificates. Documents, such as certificates of origin and phytosanitary certificates, are required for the import of fruit and vegetables for the purpose of safety and health. The certificates were issued by the inspection authority in New Zealand, to be transferred and handed over to the Belgium authorities for inspection, approval and release of the apple cargo imported to Belgium. Blockchain smart contract was employed to transfer these certificates to authorities without errors and delays (T-Mining, 2018; Chang et al., 2020).

Even though full transparency enhances transaction security, it can also be a barrier for implementing blockchain due to lack of privacy. The maritime supply chain

consists of a competitive market. Currently, many stakeholders including shippers, carriers, and consignees are not comfortable with sharing sensitive information in such a market (Yuen and Thai, 2017). The lack of planning and information flow is a large contributor to non-value adding activities in the terminal, but most parties display skepticism and opportunistic behavior in their supply chain relationships. Therefore, the information flow is limited (Olesen et al., 2012). For example, the terminal operator only communicates on the strategic and operational levels with its partners, leaving the tactical information unavailable and unused. What's more, after interviewing 31 experts in 20 companies, Loklindt et al. (2018) conclude that the interviewees believe that there have been previous attempts to facilitate sharing of information, but they often failed or their impact had been negligible on a wider scale. This could be due to the complexity and geographic scope of the maritime industry.

(d) Optimization in port operations

Port operations are challenging, because its time and space constraints are extremely complex due to the need to manage a wide range and a huge quantity of cargoes every day, each with their own specific handling, storage and deadline requirements. Ports have become bottlenecks in everyday maritime operations due to the drastically increasing cargo volume. It is estimated that the number of containers passing the port of Hamburg will increase from 9 million in 2013 to 25 million in 2025 (Lacey et al., 2015). To better optimize port operations has become a pressing issue, as shipping and other logistics companies compete fiercely for port space and resources. However, data of port operations is scattered and not efficiently shared among the stakeholders. This makes it difficult to optimize the use of available logistic resources to improve port operation efficiencies.

Blockchain can function as a single data system to transparently share the un-tampered data in real-time among port operation stakeholders. Maritime regulation requires shippers to provide accurate VGM (verified gross mass) information of packed containers to the terminal or carrier before containers can be loaded on board of a vessel. Marine Transport International, a leading freight forwarder based in the U.K. and the U.S., has begun to provide the data via the blockchain technology, which shares a permanent record visible to port officials, shippers and cargo owner. Traditionally, the VGM data is delivered sequentially to parties within the supply chain via data intermediaries, private databases, logs and spreadsheets (Finextra, 2016).

(e) Sustainability promotion

The maritime industry is one of the most polluting in the world (Czachorowski et al., 2019). Shipping and maritime transport can negatively impact the air and marine environment, by generating an immense amount of pollution (Walker et al., 2019). The most environmental impacting pollution comes from two major sources: air pollution from diesel engines and ship's illegal or improper dumping of waste into the oceans.

Maritime emissions account for roughly 3% of global carbon dioxide output (roughly the same as aviation), because ships are high polluters (Pope, 2019). Ships emit millions of tons of greenhouse gases such as sulphur dioxide, carbon dioxide and methane gases. In order to increase sustainability and improve environmental conditions, a higher-grade fuel with lower sulfur emissions has been required by new regulations for ocean carriers starting January 2020. The expected outcome is to lower sulfur emissions by over 80%. However, a higher-grade fuel costs more and that means a higher shipping cost.

It is estimated that the new fuel will cost the shipping industry extra $50 billion over the next three-to-four years (Monarch, 2020).

Blockchain promotes maritime sustainability by helping reduce various costs in the industry to balance off the increased fuel cost. First, the traceability, transparency and immutability of blockchain could minimize the costs of loss and theft, as well as detention cost in the shipping industry. The traditional paper-based tracking system lacks accountability and leads to widespread theft, graft and loss of cargos, which is estimated to cost the shipping industry more than $50 billion annually. Many shipments accrue hefty detention fees for staying overtime at a warehouse, due to the lack of visibility and traceability of the shipments. With blockchain, parties along the supply chain can track and verify the movement of cargos. Second, fewer empty shipment is possible by using blockchain to better manage asset and backhaul. It is both costly and environmentally unfriendly to move empty containers around the globe (Monarch, 2020).

Blockchain is also a possible application to aid the control of overboard discharge of waste from commercial ships. Vujicic et al. (2020) has concluded that blockchain could help protect the environment by transmitting unaltered waste discharge data to all interested parties in real time. The discharge data would be properly monitored, recorded and measured. The data can be used to obtain information of the best discharge areas for environment protection. The blockchain technology would also prevent any possible regulation violations and falsification of documents, thus ensuring environmental suitability.

3.2. Blockchain Challenges and Limitations in the Maritime Supply Chain

In this section, we discuss the challenges and limitations with which the maritime supply chain is facing to implement blockchain. The challenges and issues of governance and business processes in the maritime industry arise mainly because of its complexity (Loklindt et al., 2018).

(a) Cost of implementation

High financial investment requirements is one of the top three challenges to building digital operations capabilities in transport and logistics companies, according to a PriceWaterhouseCoopers report (PWC, 2016). Gausdal et al. (2018) confirm from their survey data that the high cost of implementation and the lack of investment initiatives are a main barrier of blockchain adoption in the maritime industry. Interviews with the representatives of Norwegian maritime companies show that costs are the primary barrier to blockchain implementation, which include costs of blockchain application development, consulting, training, specific personnel, integration with existing technologies, etc. (Czachorowski et al., 2019).

Ganne (2018) shows that companies with sufficient IT capacity and money seem to be better prepared for implementing blockchain. Even so, the world biggest shipbuilder, Hyundai Heavy Industries, still needs assistance of capital and R&D provided by the government to develop a state-of-the-art blockchain platform and to integrate the current technological infrastructure into it. Hyundai is collaborating with HashCash Consultants to develop the blockchain platform, in order to enable effective resource management and

product life cycle management (Business Insider, 2018).

(b) Laws and regulations

Maritime industry is one of the most affected industries by constantly new rules and legislations (Stevens et al., 2015). Shipping companies are governed by many laws and regulations set by national and international regulatory agencies, mainly International Maritime Organization (IMO). IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Legislation keeps updating constantly to stricter and higher standards. For example, ships will only be allowed to use fuel oil with a very low sulphur content, starting January 2020, under new rules brought in by the IMO (Monarch, 2020). Being a new technology that has recently come to existence, the governance of blockchain has not been established yet (Paech, 2017). In addition, the very principle of decentralization of the blockchain technology facilitates avoiding external regulators (Clott et al., 2020). This could definitely become a barrier for the maritime industry that has a lengthy experience of both national and international regulation (Alderton and Winchester, 2002).

"Sustainable shipping for a sustainable planet" has been selected as the world maritime theme for year 2020 by the IMO council (Maritime Executive, 2019). Blockchains consume more energy than many small countries, even though businesses conducted on blockchain today are at a low percentage. The energy requirements of blockchain could be targeted by regulatory agencies to demand lower energy usage (Clott et al., 2020). This may hinder the development and adoption of blockchain in the maritime industry, due to concern of sustainability by the shipping companies.

(c) Resistance to change

The maritime industry has a long history with a few gigantic companies. Such a supply chain is resistance to any change which is a result of complacency and individualism (Yuen and Thai, 2017). These behaviors are claimed to be the main reason for advanced supply chain integration failures (Ketkar et al, 2012). Integration can be defined from the perspective of every player in the maritime supply chain. For example, from the perspective of a seaport terminal, supply chain integration is defined as the extent to which the terminal establishes systems and processes and undertakes functions relevant to becoming an integral part of the supply chain, as opposed to being an isolated node that provides basic ship-shore operations (Panayides and Song, 2009). Seo et al. (2015) argue that although advanced maritime supply chain integration can improve competitiveness of the shipping firms in the long run, but they are unwilling to participate in integration practices such as based pricing or centralized information systems. Therefore, the blockchain technology can encounter a huge barrier in this regard, as it comes with a wave of changes.

(d) Technology challenge

The blockchain technology is still in its developing phase for data capturing and processing in the (maritime) logistics and supply chain (Dujak and Sajter, 2019). Supply chains implement various other technologies to help track products and information, such as radio-frequency identification (RFID), telematics, barcode and 2D codes, sensors, Internet-of-things (IoT), etc. This results in massive amounts of data that could slow down the blockchain network and decrease its efficiency.

Blockchain still faces technical challenges to integrate different systems, which include various software, applications,

and blockchain platforms. First, a blockchain platform needs to have the capability to customize and integrate with various different software and applications, such as ERP (Enterprise Resource Planning) or any internal systems of each participant. Second, blockchain interoperability, which is the ability to share information, operate and transact across different blockchain platforms, can be very technically challenging, although it is considered to be the next major wave of innovation that may create massive value (Chang et al., 2020). For example, it would be very difficult to integrate a shipper who operates on the Ethereum blockchain platform to a maritime supply chain that operates on the TradeLens blockchain platform.

Standardization on blockchain concepts, protocols, consensus mechanisms, legal aspects of smart contracts, and development tools could help overcome this challenge and advance the development of blockchain (Schatsky et al., 2018). As part of blockchain standardization efforts, ISO (International Organization for Standardization) established a technical committee in 2016 to develop standards on the blockchain technology and facilitate worldwide use of the technology through better interoperability. IEEE Standards Association, a standards-setting body within IEEE, has been also actively pursuing blockchain standardization efforts through various activities in multiple industry sectors.

(e) Adoption uncertainty

Lack of digital culture and training is the biggest challenge facing transportation and logistics companies, according to a PriceWaterhouseCoopers report (PWC, 2016). This makes the rate of adoption uncertain. Czachorowski et al. (2019) carried out interviews with the representatives of shipping companies, in order to find out whether Norwegian maritime companies are ready to adopt the blockchain technology. Four interviews are with offshore operators and three with suppliers. The results show that blockchain adoption in the maritime industry is uncertain, due to the lack of knowledge about the technology and cultural barrier to innovation in the shipping companies. The results also show that the following two factors may increase the likelihood and willingness of blockchain adoption in the maritime industry: (1) successful blockchain applications in other fields, and (2) through third parties who are specialized in blockchain implementation.

IV. CONCLUSION

The blockchain technology is an innovative platform for a new decentralized and transparent transaction mechanism in supply chains. Blockchain enhances trust through transparency and traceability within any transaction of data, goods, and financial resources. In this paper, we explored how blockchain could benefit the maritime supply chain. Specifically, we explore how blockchain technology provides solutions to challenges in the maritime industry, namely, reduction in paperwork and transaction time, enhanced transaction security, optimization in port operations, and sustainability promotion. We lastly discussed the challenges and limitations of blockchain adoption in the maritime supply chain, in terms of cost of implementation, privacy issues, cultural and technology challenges, laws and regulations, as well as adoption uncertainty.

We demonstrated that blockchain is a digital solution for reducing operational costs and improving efficiency in the maritime supply chain, even though the industry still faces many challenges in blockchain adoption. Specifically, blockchain implementation is still in its embryonic stage in the maritime industry.

Many companies are lacking in knowledge about the technology and face technical challenges. Extensive research and study are needed in the application and development of blockchain before its wide acceptance in the industry. The privacy issues in the maritime industry also prevent implementing blockchain since it needs full transparency. Heavy regulations in the industry can be a definite barrier for the currently unregulated blockchain technology. In addition, it is expensive to build a blockchain network and application, as well as to integrate it to the existing technological infrastructure of the companies. What's more, transaction processing in blockchain consumes a large amount of energy. This further increases the blockchain implementation cost, and may also be targeted and regulated by environmental agencies. The culture of resistance to changes and innovation in the industry also poses challenges.

Note that even though this paper focuses on the maritime industry, the discussed benefits and challenges of blockchain are general enough to be applied to other industries with a different emphasis. For example, food industry emphasizes benefits of blockchain's traceability, which provides efficient solutions for food fraud and food recalls; while banking industry benefits the most from blockchain's immutability, which allows secure and reliable financial transactions.

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