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The key challenges of blockchain implementation in maritime sector: summary from literature and previous research findings

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Abstract

The concept of transforming maritime industry into a digital platform with real-time communication has rapidly emerged within industry discussions. A big part of the topic was tied around blockchain technology that due to its decentralization feature can simplify the complexity of the supply chain network and interconnect its actors. Nevertheless, only a few studies have investigated the feasibility in detail, yet not covered limitations other than those generally discussed. The purpose of the study is to identify and summarize the challenges of blockchain implementation in the maritime industry and within maritime ports. Based on the literature and previous research findings, 18 challenges to the blockchain implementation were identified and categorized into four dimensions: human factor, operational, organizational, and technological. The findings show that different priorities among ports, low level of digitalization, scalability of blockchain systems, and unwillingness to change business routine are important challenges.

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Keywords: blockchain technology; maritime industry; challenges; barrier analysis; technology adoption

1. Introduction

The maritime sector has been a key part of the global economy and trade, where maritime actors have become larger and more relevant during the previous decades. Thus, the role of certain players within the logistic flow increases

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exponentially. For example, during the COVID-19 pandemic freight rates jumped to new heights, especially for sea container transportation, mainly due to increase in fluctuations of trade, the rapid growth of e-commerce and shortages of port infrastructure capable of accommodating the spike in demand [1; 2]. It has also affected Information Technology (IT) and its adaption in the industry – data management and forecasting have been seen as a potential to optimize the costs in the supply chains. For seaports, the stress with increasing trade was primarily addressed by investments into terminal infrastructure, also middle- and last-mile connectivity [3].

Nevertheless, for seaports the IT optimization was seen through enlarging and enhancing port community systems (PCS) – a centralized information hub that connects maritime stakeholders within a particular port e.g., port authorities, importers and exporters, customs, freight forwarders and consolidation centers [4; 5; 6; 7; 8]. PCS emphasized the importance to shift documentation to a fully digital format, hence speeding-up communication to reduce the load of terminal capacities by optimizing inner-port monitoring.

However, due to a lack of unification across the development of PCSs, the concept had not become a widespread tool [9]. The systems varied considerably in functionality, the degree of stakeholders' involvement, the coverage of ports' networks, and ultimately in ways of handling sensitive and commercial data [5; 6]. Moreover, there was a limited trust to dedicate corporate data to third-party structures such as PCS intended to be.

Information technologies in the maritime sector became a trending topic within a new attempt, that emerged in 2017, seeking to change communication and document handling not only for seaports, but for the entire supply chains. Blockchain technology, a distributed database, has been promoted to connect transportation actors, shift document flow to online platforms and automate communication throughout [4; 10]. The idea was largely supported by a considerable number of startups, and commercial and academic projects [4]. Early developments e.g., Tradelens or T-Mining, indicate that digitalization, blockchain and integration could provide notable benefits in efficiency, costs and service level [11; 7; 8]. Importantly, certain blockchain scenarios were defined exclusively for seaports as a conceptual extension of port community systems [4; 12].

Despite huge interest towards digitalized shipping industry, the literature lacks a critical overview of practical challenges that prevent the technology from adoption. Having a range of decent reviews on challenges [e.g., 13; 14; 9; 15], the literature does not reveal practical aspects with respect to seaports and its current state-of-the-art besides the generally discussed issues. Thus, the goal of the study is to recognize and summarize the field of blockchain limitations to encourage future academic and industry work to tackle the issues and assist in further development. Furthermore, the study could be of use for researchers to identify novel research pathways within the maritime sector or cross-disciplinary. The focus is kept on seaports, summarizing challenges found in literature as well as the previous research findings within the topic.

The article is structured as follows. The next Section 2 follows methodology. Thereafter, Section 3 presents findings across four main categories. Section 4 contains discussion as well as future prospects of the technology, considering the limitations. Section 5 concludes the study.

2. Methodology

The identification of challenges is the main objective of the current study. The summary of barriers will be of use for academic community and industrial practitioners to further explore the adoption of blockchain-related initiatives in global supply chains.

The study uses a combination of academic sources, previous research findings and grey literature. Since a systematic literature review relates exclusively to articles extracted from academia [16], the research method called 'multivocal literature review' implies a combination of academic sources and grey literature e.g., white papers, reports, web sources, and field-related publications [14]. In addition, considering the immaturity of blockchain technology and the fact that new knowledge comes from the general media, and is then applied in academia, the data were also extracted from industry experts' publications and blogs. The method is commonly used in education research [17; 14] and business management [18]. However, our approach in this study is different from regular literature reviews, which have a systematic approach applied in them – starting from searching and gathering of relevant studies from the area and continuing to analyze as well as report (e.g., [37]). In this research, we are more subjective and build this research work on earlier experiences from the field (e.g., projects, previous studies, theses and field visits), which are all used in the selection process of literature.

As for the collection of research findings, the method represents a summary across previous studies that aimed on revealing feasibility of blockchain technology in maritime sector. Specifically, previous research includes categorization of blockchain scenarios [4], defining and analyzing development trends of blockchain applications in maritime sector during 2018-2020. Also, the work includes conceptual prerequisites [12] i.e., what has been implemented technology-wise prior introduction of blockchain. In other words, the paper uncovers the similarity of certain blockchain scenarios to the concept of Port Community System. Moreover, the current study also summarizes the outcome of qualitative study across the largest maritime ports in Denmark [3], building knowledge on practical drawbacks from the terminal operator and port authority perspectives. Overall, the current research summarizes the barriers and challenges found across academic publications, adding new knowledge from secondary sources.

3. Challenges

3.1. Organizational

Ports prioritize land expansion. A notable barrier to the use of blockchain and various digital technologies in the supply chain is the divergence of priorities among maritime ports and carriers. Most EU ports are governmental-owned or semi-governmental, and port management is in the hands of port authority that leases the land to companies, including those that do cargo operations (terminal operators). As EU governments restrict port authorities from competing with companies based in their area, port authority is given a role of a landlord, seeking to provide all necessary infrastructure to increase the operational power and efficiency of its tenants [19].

Within the growth of global trade and constantly increasing demands for port throughput capabilities, port authorities emphasize territorial expansion as the main development priority [3; 20]. The general EU trend across small- and mid-sized ports is to enlarge the number of services provided by the port by extending the land for bulk, container and trailer cargo as well as to improve multimodality. Thus, the port development goes primarily through an increase in infrastructure capacity rather than the investments in digital solutions [3].

Customs, landside integration and final customer. Assuming a blockchain scenario with overseas coverage (from port of origin to port of destination), it can take a significant effort to include all necessary parties to a network. One of the biggest concerns is how to incorporate customs [12; 13]. Frequently, time delays occur due to freight forwarders being unable to pick up cargo as it can be taken for a customs check. The checks happen on an unpredictable manner and are poorly represented in digital format, which subsequently causes delays and fails to estimate the delivery time. With blockchain, the problem is not only to embed customs to the system, but to engage the authority to contribute, so the subsequent parties can also get information on cargo status from custom authorities.

Inclusion of landside transportation e.g., middle-mile and last-mile logistics is also a challenge. Otherwise, the advantage of partial tracking will not be clear for the final customer, which is often the consignee (store, manufacturer or an individual). Besides reduced costs, concerns of the final customer such as eco-friendliness or safety should also be included in cross-party communication [3].

One-party ownership/development interferes with blockchain decentralization. Since the beginning of considerable media attention given to blockchain, certain projects, even though announced as decentralized, focused to become an end-to-end solution [3]. For example, an industry major's Maersk blockchain was to offer a turnkey solution, implying a system, to which export authorities, import authorities, ports of destination, freight forwarders and others are connected.

While continuing to be a distributed system and spread across the established network, such a system nevertheless has one party and actor, who is “the developer, the maintainer and the implementer” of a complex system. It gives a possibility for the creator to exclude, on the long run, certain unwanted participants from the system to replace them with their own services, and therefore promote more an end-to-end solution [3]. Therefore, many decentralized projects try to offer to potential participants not only the transparency of data storage, but open access to the source code, so that the involved parties can also contribute to the process.

Bringing decentralization values along with digitalized democracy, it can, however, lead to the emergence of monopolies. For this reason, certain blockchain applications proposed to transfer the rules of maintaining or amending unified documents to state organizations, such as a port authority or local municipality [21].

Legal uncertainty. From a legal perspective, blockchain possesses challenges, in how to regulate the communication within distributed networks as the participants (nodes) are usually spread across regions and, frequently, different countries. Hence, the regulation is being applied to the country, where the node is located. This would imply that the software should be compliant with cross-countries collaboration and be aligned with their legislation [22]. Furthermore, the process of having approval procedures stored in blockchain is not yet used as legally verified evidence by the majority of, for example, European countries and the US [23; 3; 13]. Moreover, in terms of personal data use, the distribution should also be compliant with General Data Protection Regulation (GDPR) in the European Union [22].

3.2. Operational

Ports have poor level of digitalization. Besides the continuous focus on land expansion, ports significantly range by the level of digitalization. The monitoring and control over cargo through data collection and analysis varies both for the ports and the terminal operators (including those that are based in one port). Hence, the goals for ports vary. For example, certain ports are seeking the tool to reduce the frequency of equipment breakdowns, and predict timely maintenance, while others are establishing monitoring over the port gates, cargo pick-up, time-booking for forwarders, etc. [3].

Additionally, certain terminal operators and port authorities develop their own digital solutions, while others stick with a third-party developer license purchase. That also affects the extent, to which staff members are skilled with the software as well as capable of working with integrated software if it is the case [3; 22].

If blockchain is about tracking, then the industry is already doing that. When looking at existing applications of blockchain for maritime industry [4; 5; 10], most projects in their primary goals focus on either three of the aspects: document tracking, cargo tracking or shipping payments. For tracking applications, their visibility level is unclear; i.e., whether the applications are trying to achieve the tracking from: i) ocean port to ocean port, ii) ocean port to inland port, iii) port to door, or iv) door to door. While certain projects e.g., TradeLens [24] or T-Mining [21], emphasized full supply chain coverage (from manufacturer to the final customer), it has not been clarified how inclusion of other transportation modes such as rail/truck will be made [25].

In this case, if certain blockchain applications are specifically developed for tracking, then there are software solutions that can do so without decentralization. Moreover, companies deliberately store their information centralized to protect against corporate data leakage. Therefore, since the significance of blockchain decentralization is not yet clear to every party in the network, the technology also does not prevent parties from storing misinformation, i.e., creating extra confusion and security concerns. Blockchain’s resolution of fraud issue seems irrelevant as most of the fraud does not come from altering information as it passes between network parties, but rather from colluding parties entering bad information at the start [4; 26].

Unclear costs/benefits. Across the academic studies dedicated to blockchain in relation to various industries, it became evident that the technology is not a stand-alone solution, but rather an integrated part of the technological setup [27; 22].

Blockchain does not usually have a separate interface, but exists in conjunction with the software that the company/participant is working with. In fact, it shows, that in a corporate environment the users of blockchain are other software systems. Users (e.g., enterprises, authorities or individuals) do not directly work with blockchain as they do not work directly with databases such as Oracle or Postgres (SQL). The blockchain platform resides in the system architecture, and integrates with other systems, changing (or improving) the current business process.

Therefore, it is complex to track the numerical/precise impact of using blockchain in regard to the entire working system. Moreover, blockchains differ significantly by design and method of work, and therefore differ the costs associated with particular system and the network associated with it [9].

Similarity to Port Community System. Comparing current blockchain scenarios and previous attempts to digitize the shipping industry, an interesting linkage could be traced between blockchain and Port Community Systems (PCS). Even though blockchain tends to cover a wider range of supply chain parties, starting from the manufacturer and ending with last-mile delivery, when scaled to a port network, both systems show many similarities. Blockchain for document correspondence and Port Community System share common goals: To digitalize communication within port, speed-up transactions, minimize time delays and provide flexibility to the network. Both differ in the approach, where blockchain is a distributed database, and PCS is centralized belonging to one authority [5; 28].

Considering that both concepts are developing in parallel, they can supplement each other as PCS has a defined range of academic research and case studies, while blockchain is still seen as “immature technology”. Technical aspects of blockchain could be beneficial when superimposed with PCS network and vice versa [4].

3.3. Human factor

Dependency on manual input. When it comes to the human factor, regarding maritime industry, it is indicated that manual input is still a common means of handling documentation, regularly completed using e-mail, telephone calls, fax or an appropriate ERP module [24; 25]. In addition to these, in recent years popularity in the logistics sector has increased especially in web-based portals, but also different intranets and extranets have their role to play [38]. The workflow typically includes documents such as Bill of Lading, Customs Declaration, cargo certificates, transportation information and other papers related to shipment [5].

Since decentralization is established on the architectural level i.e., between existing accounting and document handling systems, blockchain systems do not imply a separate interface and are not seen as a substitute to existing software [9]. This way, it complicates the integration of parties into a network, when enterprises are not aligned on the technological level [3].

Reluctance to change business processes. Another limiting factor is general unwillingness of companies and network parties to change their business processes. Since blockchain is meant to apply to wide and diverse networks with multiple stakeholders, whether it is individuals or institutions, the integration would require a certain level of expertise, time, and human resources [29; 22].

As several studies noted [3; 22], the wider is the network, the harder it is to integrate its members on an equal basis. That is, to achieve the willingness of parties to share data, to provide full security over data exchange and have a standardized method for it [30]. Considering the size of maritime and port network, the blockchain solution will likely be an open-source database; i.e., when the initial source code is available for modifications and upgrades. Additionally, such consortia would have to follow a particular workflow: Established protocols and formats, procedures and interfaces. This might create extra difficulties for implementation, since parties operating with different software would need greater investment in upgrading equipment than others.

The level of trust is sufficient. Blockchain as technology often appeals to the problem of "lack of trust" [13] replacing the problem of relationships between multiple parties with mathematical algorithms. If there is an agreement between parties A and B, they do not delegate the execution control to party C (the third party) but establish control on the level of smart contracts. Smart contracts, following predetermined parameters, check whether the conditions are met and then execute the operation (document approval, document forwarding, parties notification, etc. [25]. A significant part of literature emphasized specifically the lack of trust toward blockchain itself mainly due to a low understanding of the technology and volatile nature of cryptocurrencies [13; 31].

Within the seaport, the problem with blockchain is that the network participants have different roles and the level of trust between them is sufficient for the current state of operations. Mostly it relates to terminal operators and port authority. Port authority typically has no extensive information on cargo volumes yet is willing to have it for infrastructure improvements and better long-term planning. However, it does not happen due to possible violation of EU port competition law, restricting port authorities from operating with cargo. In this case, blockchain has a possibility of being incorporated, providing strategic information without 1) revealing confidentiality of data, and 2) not violating competition law [3].

3.4. Technological

Scalability of blockchain-based systems. For blockchain, it remains undefined how to guarantee security, governance and risk management on a different scale. Executing blockchain is seen as complex at any of these levels [9]. Maritime and port actors vary significantly in their role and way of communicating with others. Hence it intends a potentially implemented blockchain to act differently depending on the cooperation within the network [22]. The challenge is how to provide various access to the same database depending on who is accessing it, without violating state law, mutual agreements and corporate data confidentiality. Moreover, how to set up the database in a technical way that it minimizes the delay between one component is holding one, while the other is carrying out the task [9].

Another challenge is how to verify stored information and ensure that the data can be available for staff from the various corporate levels of the same enterprise. The ability of distributed systems to gradually increase the number of members, transactions should nevertheless meet the requirements of European regulatory frameworks and global standards of data handling [32; 26].

Distributed database is confused with limited responsibility. Having a decentralized database, despite arguments supporting this type of network, can play against it in certain cases. Since data is distributed among blockchain participants on an equal basis (depending on blockchain permission type), the degree of responsibility for parties is unclear. Especially in case of system malfunctions and breakdowns as well as data leaks. The lack of a central authority could be followed by the question: "How responsibility for handling data is allocated at scale?" and hence creates a concern, if the corporate data is at risk at all times [32; 26].

Parties are likely to not run their own servers. As blockchain initially implies decentralization, which is achievable through distribution of information across the nodes (i.e., participants), bypassing the central authority. In fact, it imposes a role for all participants in such a network to become nodes i.e., “holders of the database” to confirm that historical records are identical and valid [32].

Hence, to be fully integrated into the blockchain, each participant in the network must have a copy of the database that: 1) is updated in real-time, 2) is constantly taking up more space on local hard drives, and thus 3) requires more resources for data storage management and likely its further support and maintenance.

The network initiated upon blockchain will need to develop and clarify to what extent it is easy for members to be constantly updated with the database (become nodes). Nevertheless, it implies a problem, when a decent number of potential network nodes will reject the will to constantly maintain their individual server in parallel with organization's main business [32; 26].

Low maturity of long-term projects. A significant challenge for blockchain to become a complete solution within a particular technological market segment is a lack of implementation experience, specifically regarding supply chain and maritime industry. Having the approximate start for such projects in the years 2017-2018, a big number of blockchain applications have not been reported from implementation results such have TradeLens, Blockshipping, and T-Mining [33; 21].

Currently, the majority of such projects have the status ‘in development’. It is unclear what stage of the development of the projects are, and whether they are going to be adopted. Moreover, a large share of the applications does not reveal technical details i.e., the type of used architecture, established network, pilot demonstrations, case studies, preliminary tests, etc. Thus, a big part of applications is considered as immature [12].

Participating mechanism is unclear. Blockchain by its fundamental nature promotes distributed trust and consensus without a privileged third party, providing new members with flexibility of setting up their own server and integrating it with enterprise’s existing software. However, in addition to the probable unwillingness of parties to run their own servers, the drive to simplify the workflow with blockchain might be harmful to the idea of decentralization itself [26].

Potential blockchain members, including commercial sector that are seeking to simplify the interface and interaction with the blockchain database, might eventually end up subcontracting a server setup with a third party. Due to the complexity of setting up a blockchain on an architectural level [32], companies can potentially outsource an interface from a third-party organization via API, with services and analytics included and similar access to historical records, that is built on, for example, a default Ethereum API (one of the varieties of blockchain architecture).

As a result, decentralization is handed over to a third party, whose interface integration is used to access the initial blockchain network. In turn, such a solution will make customer requests, their transactions and other data visible to the third party, eliminating the essence of decentralization.

Distributed systems are often attached to centralized platforms. Unlike blockchain projects that tend to cover cargo tracking within the whole supply chain i.e., from the production line and followed until the point of destination, thereby developing end-to-end solutions. Other blockchain platforms, primarily for commercial use, as they enlarge throughout the time, tend to centralize contrary to the original concept.

As it appeared in literature [32], a certain share of users of a particular blockchain-established service do not prioritize decentralization. As the audience grows, the original concepts of the platform e.g., distributed database, and distributed purchase process typically recede into the background, which turns the service into a centralized platform, moving it away from the original concept.

Big part of applications is attached to cryptocurrency. Even though blockchain platforms recently made it possible to handle a database without direct involvement of cryptocurrencies, many developers and startups still base their projects on tokens – analog of national currencies in digital format. This way, projects aim to monetize the business, yet simultaneously reduce the overall credibility of potential participants as well as make it difficult to legalize the earnings. At the moment, there are no direct evidence of governments supporting this payment approach. Very few countries declared it as a financial instrument [4; 22], despite its advantages in terms of operations velocity, commissions and usability [39].

4. Discussion

4.1. Overcoming the barriers

Having a wide range of various challenges slowing the adaption of the technology, there are, however, options to overcome part of these issues. Firstly, as a technology that tends to connect multiple parties around a software solution, it requires partnerships to spread the product to maritime port actors and local communities. So, the success is heavily dependent not as much on the rates of blockchain development, but on leveling all required actors to a common level of work with digital data. That is, the organizational and technical barriers refer to more fundamental problems – the strong spread between actors in the network and how deeply they work and store digital information. Government organizations and frameworks can facilitate a faster transition to digitalization, which, consequently, could contribute to a further foundation for decentralized systems.

As for networking, it was proposed in academia to largely incorporate customs into the digitalization of port network as a considerable part of delays happen on an unpredictable manner due to customs inspections. In this case, customs, similarly to port authorities, could play an important role regarding setting up the framework for documents that can be unified [34].

Considering the distributed nature of the technology, being the new "digital democracy tool", it boosts the potential for blockchain through open-source access and collaborative developments – meaning repositories, largely on the part of big companies, to allow ordinary users to contribute to the code and have access to build algorithms, as it happens currently with several decentralization approaches like Hyperledger. In many ways, the possibility and prevalence of open-source development significantly affects the popularity growth of a particular technology. Thus, the higher the support of open-source mechanisms (financially or media-wise), the better it is for the final users.

Cooperation with consulting companies related to blockchain adoption could eliminate some of the potential barriers, or at least, fill up the knowledge gap for decision-makers. Another way to look at it is by adding value to the company. Developments and pilot demonstrations could attract more investments rather than the fear of company's personnel risking losing jobs due to automation.

As described in the findings, the spread of blockchain developments by industrial companies could be considered as forcing an end-to-end solution with consequences of exempting certain parties from the network (e.g., mediators in the supply chain). Yet, with governmental support, the picture could get a more positive impact. For example, international maritime councils such as IMO or BIMCO could significantly contribute towards the involvement of different maritime organizations and blockchain providers [15]. Also, as followed from [15], a great attention should be paid to local policymakers with the emphasis on financial support and subsidies for enterprises, who incorporate blockchain applications; "provide tax reliefs and direct investments in blockchain".

Even though some of ideas can probably support blockchain technology in the marketplace, subsidies are not always the right way, since it is the commercial demand that shows the value of the product. Government investments, if happen, should be in balance with ongoing commercial demand – that is, to not fully cover development of the technology, especially when its applicability is still unclear.

4.2. Link to previous research and future prospective

Blockchain technology, especially scenarios emphasizing digitalization of sea trade and having a high similarity with Port Community System, are basically seen as two technologies overlapping by the purpose of use. In this case, the concepts can potentially superimpose on each other, taking each other's technical and/or business developments [12].

Figure 1. The likely scenario of further development of digital solutions for the maritime and supply chain industry

The continued emergence of technologies seeking to improve supply chain communication and digitalization speaks to the gradual progression of the industry. The widespread publicity of ongoing blockchain projects in the media, startup applications, academic studies signal the relevance for the solutions in the field, whether it is a blockchain, port community system or a hybrid between the two.

Given the large number of challenges hindering the adoption of the technology, it is likely that a scenario will emerge where solutions take previous developments, considering the problems, and give a boost to the development of the maritime industry to become more digitalized and data-driven (Figure 1).

5. Conclusion

Considering the findings and challenges towards blockchain adoption, both organizational and practical as well as technological and structural, it significantly complicates the subsequent implementation of the proposed scenarios.

Furthermore, in order to solve the existing problems, blockchain introduced a series of new challenges. The technology still has the status of being "immature technology", and if not implemented or only partially implemented, it nevertheless gives impetus to the next generation of solutions. Wide publicity and growing popularity in media also contributed to a fact, when supply chain as an industry gained a new segment of the market filled with IT solutions competing with each other. Having that, contribution of blockchain to the field is seen effective and positive.

The study has some limitations. Mainly, it contains the lack of peer-reviewed articles from academia regarding certain blockchain challenges. Also, what could be of concern is the theoretical and descriptive nature of the study, even though some results are taken from previous qualitative studies. Having that, the research could be improved by a validation round i.e., another qualitative analysis with industry experts. However, the industry lacks theoretical studies on the blockchain implementation within maritime industry, which makes the study worth as a contribution.

As for future research, the majority of the above-mentioned challenges represent a decent research gap for future analysis. The biggest opportunities lay within how realistically possible the cooperation between port actors in terms of data exchange: customs, port authority, freight forwarder and terminal operator.

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