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Blockchain adoptions in the maritime industry: a conceptual framework

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ABSTRACT

Blockchain technology has become one of the emerging technologies set to disrupt the maritime industry. Maritime companies are increasingly exploring to adopt blockchain to stay ahead of competition. However, studies on blockchain applications in the maritime sector have been scarce and most of them are confined to a specific sector like the maritime shipping sector. Therefore, this study is motivated to provide a thorough analysis of blockchain applications from the perspectives of different sectors in the industry. It also aims to develop a novel conceptual framework to provide a holistic view of blockchain adoption in the industry and guide future research. The implication analysis of blockchain adoption indicates that for industry organisations, a good understanding of blockchain and their own specific problems and requirements is key before adopting the technology. For government agencies, technical code for blockchain can be utilised to govern blockchain innovation with the same effects as legal code. Lastly, recommendations are provided to various maritime stakeholders to seize the emerging opportunities provided by blockchain and mitigate relevant risks.

KEYWORDS

Blockchain; distributed ledger; maritime; shipping; technology adoption

1. Introduction

With the emerging challenges and uncertainties from the slow growth of international trade, increasing protectionism, tightening environmental regulations and the recent outbreak of COVID-19 pandemic, the maritime industry has to look for innovative ways to stay competitive in the fast-changing world. The industry is seen making efforts to embrace the emergence of Industry 4.0 to revolutionise itself. Blockchain technology has become one of the promising technologies to facilitate the digital transformation of the industry. With its huge potential to address the industry concerns regarding trust, data integrity, traceability, timeliness and transparency, it is set to bring the industry to the next era of digitisation, together with other information technologies.

The concept of blockchain was first introduced by Satoshi Nakamoto in 2008. Since then, it develops to one of the computing 'mega-trends' which is possible to shape the world in the next 10 years (World Economic Forum 2015). Industries are increasingly interested in leveraging blockchain to transform their core business operations owing to its features including security, transparency, traceability, and smart contracts. Its applications have expanded from cryptocurrency to areas including identity management, health care, government election, insurance and logistics.

For maritime supply chains, blockchain is expected to address industry concerns like intensive paperwork, tedious processes, and data transparency. It enables maritime companies to differentiate

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their services and reduce costs at the same time, which is the most desirable hybrid business model for shipping companies (Lam and Wong 2018). It is also a technological advancement to authenticate and validate information (Apte and Petrovsky 2016), which is a main problem of the current supply chain (Wu et al. 2017). As such, more and more maritime companies started to join the wave of blockchain, such as Maersk, NYK, ZIM, APL and Port of Rotterdam (Xu 2017; Seatrade 2017). Some alliances (e.g. Global Shipping Business Network (GSBN)) have also been formed to better discover the potential of blockchain in the industry.

Despite increasing blockchain pilot tests to address several maritime problems, the literature related to blockchain in the industry is limited. Gausdal, Czachorowski, and Solesvik (2018) study the benefits and inhibitors of blockchain adoption in Norwegian marine offshore sector, while Papathanasiou, Cole, and Murray (2020) analyse the same topics for the Greek shipping industry. Tan, Zhao, and Halliday (2018) propose a blockchain model to simplify the less than container load export process. Yang (2019) investigate maritime organisations' intention to use blockchain. Besides, a few papers point out some potential use cases of blockchain in the industry, mainly about tracking and tracing information and digitising documents (Gausdal, Czachorowski, and Solesvik 2018; Jabbar and Bjørn 2018; Wang and Qu 2019; Maydanova, Ilin, and Lepekhin 2019; Czachorowski, Solesvik, and Kondratenko 2019).

Previous studies mainly discuss blockchain's applications in the maritime industry from a specific point of view, such as Norwegian offshore sector, Greek shipping market and shipping logistics. Few consider blockchain's applications in other maritime sectors like ship finance and marine insurance. As such, this study is motivated to narrow the research gap by answering the following research questions: 1) how can blockchain be applied in different sectors of the maritime industry? 2) why is it suitable for these applications? and 3) what are the research opportunities in this field? Hence, this study aims to thoroughly analyse current and emerging blockchain applications in different sectors of the maritime industry and develop a conceptual framework to provide a holistic view of blockchain adoption in the industry and guide future research.

This research applies a methodology of content analysis based on the four-step process model used by Seuring and Gold (2012) to perform a systematic analysis of blockchain applications in the maritime industry. The four steps include material collection, descriptive analysis, category selection and material evaluation. When collecting material, the focus is on English articles relating to blockchain adoptions in the maritime industry from academia and industry. The keywords for search after trial and errors are identified in two groups—one includes blockchain and distributed ledger; the other includes maritime, shipping, port, ship and vessel. Using different pairs of keywords from the two groups, related academic papers are searched in the fields of title, keywords and abstract in Scopus database, which has a broader coverage than Web-of-Science database (Aksnes and Sivertsen 2019). Then related commercial publications, newspapers and magazine papers are searched in Google. According to the research objectives, the analytic categories are blockchain use cases, reasons for application and participating companies. The official websites of participating companies are also searched for useful articles to supplement the material. Then collected material is evaluated with an inductive approach which derives results through a detailed examination of material (Thomas 2006). The different categories of blockchain applications are also derived inductively along with authors' experience in the industry.

The remaining of this paper is arranged as below: Section 2 provides an overview of Blockchain Technology. Sections 3 and 4 analyse the current and emerging blockchain applications in the maritime industry. Section 5 presents a novel conceptual framework for understanding blockchain applications in the maritime industry in a holistic view and provides future research suggestions. Section 6 discusses the implications of blockchain adoption for organisations and governments. At last, section 7 concludes the study with main contributions.

Table 1. Key features of blockchain technology that are relevant to the maritime industry.

Key Features of Blockchain	Relevance to the Maritime Industry (Examples)
Distributed System	Build a cross-national platform for information sharing related to maritime surveillance and maritime trade
Immutability	Track and trace information; Issue digital certificates
Peer-to-peer transmission	Transfer bills of lading; direct cross-border payment
No single point of failure	Enhance maritime cybersecurity
Time-series data	Track and trace information; record the history of bills of lading
Visibility	Provide real-time shipping information to involved parties; Enhance information sharing in the industry
Anonymity	Provide a guaranteed anonymous channel for whistleblowing
Smart contracts	Adjust marine insurance premium automatically and settle payment automatically

Source: Features are compiled by authors based on (Xu et al. 2016; Berke 2017; Xu et al. 2017) and the relevance to the maritime industry is from authors.

2. An overview of blockchain in general

Blockchain is defined as a distributed database solution that holds a continuously growing list of data records which must be confirmed by all participating nodes (Yli-Huumo et al. 2016). In order to be recorded in the chain, transactions have to be confirmed by the nodes participating in it (Yli-Huumo et al. 2016). The technical features of blockchain and their relevance to the maritime industry are summarised in Table 1.

Based on the different openness of network, blockchain can be classified into two categories, namely permissioned and permissionless (Xu et al. 2016). Table 2 summarises the major differences between the two types. Compared with permissionless blockchains, permissioned ones are more congruent with the current regulatory environment because of the use of actual entities of participants (Ducas and Wilner 2017). Hence, they can legally host off-chain properties in the real world, which makes them more suitable for business enterprises. Besides, they also provide flexibility for owners to change rules and reverse transactions (UK Government Office for Science 2016). Therefore, permissioned blockchains are more suitable for business enterprises which require higher performance in privacy, speed, and regulation conformance; permissionless blockchains are more suitable for activities which require a high level of transparency and audit.

Next, four distributed ledger platforms, namely Hyperledger Fabric, Corda, Ethereum and Ethereum Quorum, are introduced as they are the most popular ones used in the maritime industry based on the findings of Section 3. It is worth to mention that Corda is not a blockchain but another type of distributed ledger technology, as its transactions are not grouped in the form of blocks. Corda and Hyperledger Fabric support Java to develop smart contracts, which makes them easy to be implemented as Java is a mainstream programming language (Swan 2018). Ethereum and Ethereum Quorum are based on Ethereum protocol, which is more developed with regard to codebase, user-base and developer community compared with the other two systems (Vukolić 2017). In terms of smart contracts, Corda not only includes technical codes but also contains legal prose in natural language (Valenta and Sandner 2017), while the other three systems lack this

Table 2. Comparison of permissionless and permissioned blockchain.

Properties	Permissionless blockchain	Permissioned blockchain
Consensus Process	Open to public	Only open to pre-selected validators
Right to write and read	Open to public	Only open to whitelisted organisations
Ability to host real-world assets	No	Yes
Ability to reverse transactions	No	Yes
Cost efficiency	Less favourable	More favourable
Speed	Slower	Faster
Openness	Higher	Lower

Source: Compiled by authors from (UK Government Office for Science 2016; Ducas and Wilner 2017; Xu et al. 2017).

Table 3. Comparison of distributed ledger technologies for maritime industry.

DLT* Features	Ethereum	Ethereum Quorum	Hyperledger Fabric	Corda
Permission	Permissionless	Permissioned	Permissioned	Permissioned
Built-in Cryptocurrency	Yes	Yes	No (but possible to develop one with chaincode)	No
Smart Contract Execution	Ethereum Virtual Machine (EVM)	EVM	Dockers	Java Virtual Machine (JVM)
Smart Contract Language	Solidity	Solidity	Golang, Java	Kotlin, Java
Consensus	Hybrid PoW*/PoS*	Raft (similar to PoS)	Practical Byzantine Fault Tolerance (PBFT)	Raft (similar to PoS)
Transparency level	Public	Public or Private	Need-to-know basis	Need-to-know basis
Scalability	Less Favourable	More Favourable	More Favourable	More Favourable

*DLT: Distributed ledger technology; PoW: Proof of Work; PoS: Proof of Stake
Source: Compiled by authors based on (Valenta and Sandner 2017; Swan 2018; Dinh et al. 2017).

feature. This makes Corda more attractive in heavily regulated industries. A summary of the important features of these platforms is provided in Table 3 for ease of comparison.

3. Current major blockchain applications and their benefits in the maritime industry

Since 2017, blockchain use cases have been gradually developed and tested in the maritime industry as shown in Table 4. These cases mainly fall into four fields: 1) electronic bills of lading, 2) ship operations, 3) ship finance and 4) marine insurance. The discussion below analyses the current challenges in the maritime industry and how blockchain helps to overcome these challenges in each of the fields.

3.1. Electronic bills of lading

Because of the legal importance of bills of lading, it is discussed separately in this section rather than being included under shipping operations. In the paper bills of lading system, delays often happen because of the long processing and physical delivery time (Reed Smith 2016). Although earlier attempts from Bolero, essDOCS, and e-title™ to build electronic bills of lading (e-BL) systems have been gradually used to address this problem, concerns of insider fraud and confidentiality exist in these e-BL systems (Pagnoni and Visconti 2010; Dubovec 2005). These systems rely on a central party to transmit original bills of lading. Users have no or limited control over the process within the central platform and all messages can be read by the core messaging platform.

Blockchain could mitigate the risks of insider fraud by enabling direct peer-to-peer communication without any central parties. At the same time, blockchain can address the confidentiality issue as information can be secured by one-way cryptography and can only be decrypted by the specified recipient (Christidis and Devetsikiotis 2016). Current cargo owners can endorse e-BLs with its own digital signature and include the public key of the next owner in the transaction. With that, the transference of e-BLs will be recorded in the blockchain in chronological order and can be used to trace the ownership history by verifying signatures.

3.2. Ship operations

3.2.1. Reducing paperwork

The operational processes of shipping are archaic. A single transaction can create a pile of papers such as sales agreements, bills of lading, charter parties, customs clearance documents, and letters of

Table 4. Examples of typical blockchain use cases in the maritime industry.

Application Areas	Specific Use Cases	Companies	Platform Used	References
Bills of Lading	Electronic Bills of Lading	Bolero	Voltron (based on Corda)	(Global Trade Review 2019)
		CargoX	Ethereum	(CargoX 2018)
		A.P.Møller-Maersk (TradeLens)	Hyperledger Fabric	(Maersk 2018)
		American President Lines (APL)	Corda	(Accenture 2018)
		Blue Water Shipping Louis Dreyfus	Ethereum Quorum	(CoinDesk 2018)
		PIL	Hyperledger Fabric	(Seatrade 2017)
Ship Operations	Reducing Paperwork	A.P.Møller-Maersk (TradeLens)	Hyperledger Fabric	(Maersk 2018)
		DNV GL	Vechain Thor, Ethereum-like	(Global Trade Review 2019)
	Enhancing Info Sharing	Kuehne + Nagel (Sharing container verified gross mass)	Hyperledger Fabric	(Ledger Insights 2018a)
	Track and Trace Information	A.P. Møller-Maersk	Hyperledger Fabric	(Maersk 2018)
		Pacific International Lines PSA International Pte Ltd	Hyperledger Fabric	(Seatrade 2017)
Marine Insurance	Underwriting Claims Fraud Reduction	A.P. Møller-Maersk Willis Towers Waston MS Amilin XL Catlin	Corda	(Seatrade 2018a)
		B3i Services AG	Corda	(B3i.tech. 2018)
		RiskStream Collaborative (former RiskBlock)	Corda	(Ledger Insights 2018b)
Ship Finance	Cross-Border Payment	Ripple Labs, Inc	Ripple	(Caron 2018)
	Ship Financing (ICO)	Shipowners.io	Ethereum	(Splash247 2018)
	Escrow Account	300cubits	Ethereum	(John 2017)

Note: Platforms used by companies may be changed in the future.
Source: Authors, based on online news and companies' official websites and white papers.

credit. Traditionally, the shipping industry relies heavily on physical movements of paper documents. Those papers must pass through a long chain of workflows for approval, processing payments or customs clearance. The whole process is vulnerable to human errors, fraud and inadvertent delays (Lam and Zhang 2019). The waiting time for processing documents was approximately 29% of the total delivery time from exporting farm to retailers (Park 2018). The costs of paperwork were estimated 15% to 20% of the total shipping fee (Longman 2017). Therefore, there is an opportunity to improve efficiency and save costs in shipping via reducing paperwork.

Blockchain comes into play to solve this problem in various ways. Firstly, it could make the whole process paperless in a tamper-proof way. Participants can use the public and private keys to safely communicate with each other, perform transactions, transfer documents and execute payments. Secondly, blockchain provides full transparency in the business. The on-chain information of transactions and ownership transfers is visible to all the accessing parties. Real-time updates and notifications are easy in a quick click. Thirdly, with the adoption of smart contracts, standard shipping contracts could be generalised in a coding format and players can have the freedom to negotiate price directly on the blockchain network.

3.2.2. Information sharing

Many studies highlight the importance of information sharing to enhance supply chain integration and the overall operations performance (Prajogo and Olhager 2012; Lai, Wong, and Lam 2015; Wu, Chuang, and Hsu 2014; Jeong and Leon 2012; Narasimhan and Nair 2005). If information can be shared effectively, shipping costs could be reduced by up to US$300 per container (Seatrade 2018b). Through sharing container capacity alone, the container business is expected to save nearly US $6 billion and reduce about 4.5 million tonnes of CO_2 emissions every year (Lewis 2018). However, lack of trust has been a main barrier to hinder companies from sharing information (Wu, Chuang, and Hsu 2014).

Blockchain could address the problem by building trust among participants (Kshetri 2018). This is achieved through data integrity, reliability, responsibility and predictability, which are antecedents of trust (Beck 2018). Moreover, it could not only integrate operational, informational and financial shipping data in a worldwide platform (Tan, Zhao, and Halliday 2018) but also provide security of data storage and transmission. Blockchain allows real-time update of information and such record is transparent and effectively unmodifiable. When a new status of a particular container is uploaded through sensors, the information will be automatically propagated to the involving parties.

3.2.3. Track and trace cargoes

One main challenge in logistics is to monitor product quality and track their physical movements until reaching end-users (Shankar, Gupta, and Pathak 2018). However, the current information systems are not able to provide valid and real-time shipment tracking during the transportation phase (Wu et al. 2017). This leaves the window open for fraud, which could cause serious financial losses to the genuine companies (Kshetri 2018).

Blockchain could improve the current tracking system in supply chains by keeping an immutable and traceable record of product movements from origin to end customers on a real-time basis. Every product is tagged with a unique ID and scanned at each transportation stage. The scanning data is then recorded in a distributed ledger and shared amongst parties in the transaction chain. It is possible to add more comprehensive data such as product temperature and container empty status. Therefore, blockchain serves as a trustful channel to check the genuineness of products, prevent the risks of counterfeiting and monitor the product quality along with the transportation phase.

3.3. Ship finance

3.3.1. Ship financing

The main resources of ship finance have traditionally been and are still banks (Kavussanos and Tsouknidis 2016). However, nowadays banks are seen to limit their funds to the shipping industry due to stricter financial regulations like Basel III (Lozinskaia et al. 2017). Although there is an increasing trend for shipowners to raise funds by Initial Public Offering (IPO) or issuing bonds in capital markets (Albertijn, Bessler, and Drobetz 2011), this method does not suit most shipping companies because they are relatively small in capital markets (Stopford 2008). Blockchain provides an alternative way of financing shipping companies through Initial Coin Offering (ICO). ICO is realised in a blockchain-based trading platform by issuing digital tokens, which is similar to IPO in the stock market by issuing shares. Compared with IPO, ICO cuts intermediaries, makes cross-border transactions easy, and provides high transparency and liquidity.

3.3.2. Cross-border payment

Currently, the cost of cross-border remittance is 5%—20% of the amount remitted (Martin 2017) and it takes a few days to reach the destination. Via intermediary cryptocurrency, the cost can be reduced to 2%—3% and the payment is nearly real-time (Martin 2017; Yuan and Wang 2016). Hence, blockchain provides a faster, more economical and safer solution for cross-border payment than current SWIFT systems (Yuan and Wang 2016).

3.3.3. Escrow

The cryptocurrency function together with smart contracts could be used as a trustful escrow account for solving disputes or managing deposits. For instance, the defaulting problem in container booking could be addressed by using blockchain. No matter who defaults in the end, the deposits in the form of cryptocurrency will be payable to the counterparty under a smart contract. If a container booking is fulfilled successfully, the deposits in cryptocurrency will be returned to the parties respectively (Wainwright 2018).

3.4. Marine re/insurance

The current popular blockchain applications in marine re/insurance industry lie in the following three areas: underwriting, claims management, and fraud reduction.

Underwriting evaluates the risks of insuring a company, an asset, an activity or an individual; and it determines whether the insurers should take the risks, how much coverage the client can get and how much the client should pay. Efficient data sharing enables a faster and more accurate underwriting process. With blockchain, the underwriting process becomes simplified since the information in the system remains verified and integrated and the record of policy applicants can be easily traced (Nath 2016). Automatic adjustment of premium can also be achieved based on the behaviour of the insured (Püttgen and Kaulartz 2017). For instance, it is possible to use blockchain to automatically charge an additional premium for vessels entering the high-risk area of piracy if GPS data is fed in the system.

Processing insurance claims often involves many parties such as insurers, policyholders and other third parties. However, the transparency of required information to process claims is currently insufficient among the participants (Nath 2016). With blockchain, claim activities and supporting documents will become transparent to relevant parties. Besides, smart contracts can assist to accelerate the process of reviewing and approving claims and thereby to shorten the time to resolve a claim (Püttgen and Kaulartz 2017).

Fraud is a big problem in the insurance industry in general (Henry and Hogan 2018). Blockchain could address this problem due to its ability to provide cryptographic authentication and data transparency. With blockchain, insurers could easily verify identities, identify double claims, detect patterns of fraudulent behaviour, share indicators of potential fraud, and hence collaboratively reduce fraud (Henry and Hogan 2018).

3.5. Distributed ledger platforms used by maritime companies

According to Table 4, permissioned systems appear more widely used by maritime enterprises than permissionless systems. This could be because permissioned systems provide better privacy and have a better performance in speed, throughput and scalability.

Among the permissioned systems, Corda and Hyperledger Fabric are more popular in the maritime industry. This may be partly attributed to their ease of usage and interoperability with companies' current IT systems (Valenta and Sandner 2017). Besides, Corda appears popular in the marine insurance sector, which may be because it provides better legal functions supported by legal prose in natural language in smart contracts. As such, it has great potential to be applied to other legal shipping documents such as bills of lading and charter parties. The popularity of Corda, a non-blockchain distributed ledger, indicates a trend that distributed ledger systems other than blockchain may be increasingly applied in the industry in the future.

It is also interesting to note that although permissioned systems may be more suitable for business enterprises, there are still some companies choosing public blockchain Ethereum for their projects. These projects are mainly related to ship finance or payments. This is reasonable considering the maturity of Ethereum as a cryptocurrency and its well-established standards for smart contracts. However, Ethereum's position in ship finance and payment sector may be threatened by other blockchain platforms such as Ripple in the future because the latter is specifically designed to meet the stringent regulations in the financial industry.

4. Emerging trends of blockchain applications in the maritime industry

The implementation of blockchain in the maritime industry just started. Apart from the use-cases mentioned in section 3, integrating blockchain with other technologies, such as the Internet of Things (IoT), smart grid and 3D Printing, is an emerging trend.

Blockchain provides a favourable solution to address some limitations and enhance the performance of current IoT systems. For example, it could solve the current synchronisation problem in IoT (Huh, Cho, and Kim 2017). It could also improve the internal and external interactions between smart devices in the IoT system (Teslya and Ryabchikov 2017). With increasingly cheaper and more accurate sensors, IoT will be more widely adopted in the maritime ecosystem (QinetiQ, Lloyd's Register, and University of Southampton 2016). If shipping lines and ports could incorporate blockchain into their IoT systems, they can achieve more efficient real-time monitoring, tracking and tracing.

Due to blockchain's property of decentralisation and cryptographic identity, the technology is hopeful to overcome the current main constraints of smart grid as a centralised energy system—single point of failure and low privacy (Aitzhan and Svetinovic 2016). It could also enhance real-time monitoring which plays an important role in smart grid operations (Pop et al. 2018). By adding smart contracts into smart grid, distributed nodes are able to communicate among themselves and even make local decisions on how to distribute electricity during peak and non-peak periods (Prousalidis et al. 2017).

With the onset of 3D Printing technology, some maritime players such as classification societies like DNV GL and terminal operators like PSA are looking to leverage this technology for manufacturing marine parts and even vessel building (Maritime and Port Authority of Singapore 2018; DNV GL 2018). However, the mass adoption of 3D printing was hindered by the absence of seamless and secure data transformation (Deloitte 2016). Blockchain provides a good solution for this problem because 1) it enables seamless 3D printing with nearly real-time data transfer, and 2) it provides a protection layer to data storage and transfer with immutability and cryptographic authentication. Maritime manufacturing stakeholders should keep an eye on the developments of blockchain, which may become the backbone to safeguard marine 3D printing processes.

5. Conceptual framework and future research suggestions

The analysis of sections 3 and 4 indicates that the majority of maritime blockchain applications revolve around three themes: reducing paperwork, enhancing information sharing, and automating processes; and the ultimate goal is to achieve a lean process. On top of this finding, a conceptual framework is developed, as shown in Figure 1, to provide a holistic view of blockchain adoption in the industry. Future research suggestions are provided based on the framework.

The framework uses Moon and Ngai's (2008) framework for RFID as a reference, which shows how RFID generates values to the fashion retailing industry. Besides, technical features are included in the framework based on two popular technology adoption models—Technology Acceptance Model (TAM) and Technological, Organisation and Environment (TOE) model. Both models emphasise the importance of technical characteristics of a new technology to the technology adoption (Depietro, Wiarda, and Fleischer 1990; Venkatesh et al. 2003). In addition, the understanding of a new technology's application requires the knowledge of stakeholders (Troshani and Doolin 2007). Therefore, stakeholders are also considered in the framework.

The conceptual framework consists of five dimensions: technical features of blockchain, commercial benefits of blockchain to the maritime industry, applicable areas in the maritime domain, major maritime stakeholders involved in these applications, and potential adoption challenges in

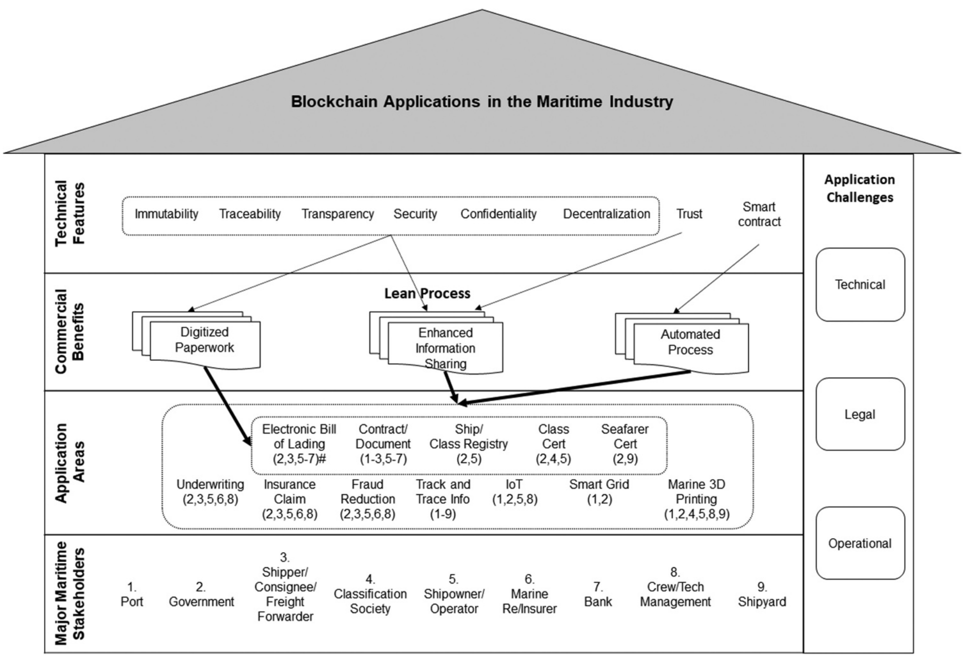

Figure 1. A conceptual framework of how blockchain can be utilised in the maritime industry with application examples. Source: Authors. Note: The arrows indicate a link between items from two different layers. A thick arrow denotes that the commercial value could be applied to all the application areas in the directed box.#: the numbers in bracket represent the corresponding major maritime stakeholders of each application area.

the industry. We derive the relationships between these dimensions and their effects on blockchain adoption in the maritime industry by examining the detailed factors in each dimension.

The result of the analysis shows that the technical features of blockchain form the foundation for creating commercial benefits for the maritime industry. The ultimate commercial benefit of blockchain is identified as achieving a lean process through three aspects: digitising paperwork, enhancing information sharing, and automating processes. The relationships between the technical features and the commercial benefits are proposed in the framework based on the analysis in section 3 about how blockchain could generate commercial benefits to address the current problems in the maritime industry. First, the technical features of blockchain including immutability, security, confidentiality and decentralisation could safeguard the digital system for paperwork as they ensure that documents are tamper-proof, accessible only to pre-selected participants and free from single point of failure (Berke 2017). The immutability, traceability and transparency provided by blockchain could ensure the system efficiency as they facilitate data verification (Liu et al. 2017) and eliminate duplicate data entries (Banerjee 2018). Thus, the six technical features mentioned above are supposed to have a positive effect on achieving digitalised paperwork in the industry by providing a more secure and efficient platform to manage paperwork. In addition, blockchain could build trust among users (Kshetri 2018) by providing confidence, integrity, responsibility and predictability, which are antecedents of trust (Beck 2018). Efficient information sharing is based on not only a secure and efficient digital system but also trust between players. Thus, the technical features useful for building a secure and efficient platform and the trust feature enabled by blockchain collectively form the foundation for promoting information sharing in the industry. At last, since automation in blockchain is realised through smart contracts (Christidis and Devetsikiotis 2016), it is suggested that a higher level of smart contracts used would lead to a higher level of automation in the industry. Based on the above analysis, we propose that 1) blockchain's immutability, traceability, transparency, security, confidentiality, and decentralisation are positively associated with achieving digitised paperwork in the maritime industry; 2) blockchain's immutability, traceability, transparency, security, confidentiality, decentralisation and trust are positively associated with achieving enhanced information sharing in the maritime industry; 3) blockchain's smart contract is positively associated with achieving automated processes in the maritime industry. The positive association between the technical features and the commercial benefits means that the higher level of the technical features helps in achieving better results in the corresponding commercial benefits. Since the proposed relationships are derived from qualitative analysis, future research could consider empirical testing for these relationships.

The analysis identifies contextualised application areas of blockchain for each commercial benefit. Digitising paperwork could be realised in many areas such as ship registry, classification certificates, bills of lading, seafarer certification, and shipping contracts. Enhancing information sharing can be applicable to the whole maritime supply chain. This includes all the application areas in the framework because maritime transportation and relevant marine services rely on shared information to coordinate throughout the chain. The information ranges from commercial information such as cargo movements to technical information such as engine data. In addition, there is potential to realise a certain degree of automation along maritime supply chains. For instance, through the use of smart contract, payment transfer of freight and insurance premium can be automated between two relevant parties. While some above-mentioned application areas like electronic bills of lading and digitising ship registry process have been tested in the industry, others need to be explored further in future research. For instance, researchers could consider investigating the possibility of integrating blockchain with other emerging technologies to deal with the vulnerabilities of current maritime systems or revolutionise the way of doing business and handling operations. One specific example is to analyse how effective it is to integrate blockchain with smart grid to better realize smart distribution and trading of electricity in ports. Besides, future research could look to quantify the commercial impact of blockchain in each application area in the framework and investigate whether and when maritime organisations should adopt the technology in the area.

Our study stresses the importance of stakeholder management in blockchain adoption. The knowledge of stakeholders, their market power, differences and possible attitudes, help to understand the potential impact of them on the adoption process (Troshani and Doolin 2007). The major maritime stakeholders in each blockchain use case are identified based on their relevance to each case. For example, the major stakeholders in the marine insurance underwriting use case are recognised as shippers, consignees, freight forwarders, ship operators, marine re/insurers and ship technical management companies. These stakeholders need to purchase certain marine insurances for either marine cargoes or vessels related assets. Before embarking on blockchain adoption, decision makers need to understand the differences and possible reactions of stakeholders to better manage the potential conflicts and issues from stakeholders. Future research could investigate the impact of blockchain on different maritime stakeholders and analyse the interaction among stakeholders for blockchain adoption and implementation.

Our analysis also shows that blockchain adoption entails challenges in the maritime industry mainly from legal, technological and operational aspects. Uncertainties exist in terms of legal enforcement, insurance cover, and loose regulations on ICO (Reed Smith 2016; Wall Street Journal 2018). Major technological concerns centre around security, scalability and interoperability (Deloitte 2017; Kshetri 2018; Xu et al. 2017). Operationally, it is challenging to achieve widespread adoption due to push back by the current shipping infrastructure (Jabbar and Bjørn 2018) and potential conflicts among different stakeholders. The applicable cases of blockchain may also be limited to a certain level due to the complexity of shipping business in reality. The extent of these challenges would be different in different use cases. The conceptual framework provides a starting point for the industry to better identify the potential challenges for a specific use case and suggests collaborative efforts to overcome these challenges as various stakeholders are involved in the applications. The field of adoption challenges of blockchain has not been analysed deeply in the maritime context. Future research could examine the impact of these challenges on blockchain adoption in different use cases and investigate potential measures to tackle the challenges for faster and wider adoption of the technology.

With the five dimensions, the conceptual framework answers the fundamental questions of why, how and who regarding blockchain's adoption in the maritime industry. Ample future research opportunities are identified ranges from testing proposed relationships, examining the possibility and effectiveness of technology integration, quantifying the commercial benefits, exploring emerging applications, investigating when to adopt the technology for each use case, conducting stakeholder analysis to analysing measures to overcome the adoption challenges.

6. Implications and recommendations for maritime stakeholders

Although the conceptual framework indicates many opportunities provided by blockchain, the adoption of blockchain remains challenging. The following sections discuss the implications of blockchain adoption for individual organisations and governments, and provide detailed recommendations for different maritime stakeholders.

6.1. For individual organisations

Although facing challenges, maritime organisations should ride on the wave of blockchain to speed up their digital transformation and improve their competitive advantage in the industry. Before adopting blockchain, it is necessary for companies to have a thorough understanding of the technology itself and their own specific requirements such as wherewithal, transparency, privacy, scalability and interoperability. When it comes to the specific design of distributed systems, companies need to consider the technical requirements of platforms systematically and assess their impacts on the overall incumbent systems (Xu et al. 2017).

Besides, legal effects must be considered since the same system will be covered by multiple jurisdictions simultaneously. However, the current legal frameworks in most countries are not fully ready to effectively handle blockchain transactions, even though some of them are implementing proactive policies. To avoid potential legal matters, companies can start with simple use cases first. For example, when APL and PIL started their pilot tests on blockchain bills of lading, they chose to deal with non-negotiable bills of lading first so that they do not have to worry about the legal issues related to transference of title of goods.

In order to make blockchain fully effective, each maritime organisation should proactively seek cooperation with clients, governments and even competitors to share knowledge and establish standards, as the benefits of blockchain cannot be significant without reaching a critical mass.

6.2. For government agencies

The roles of them for blockchain applications are mainly in two aspects. One is to explore the possibilities to incorporate the technology into the public sector. The other is to effectively govern the use of the technology as well as to promote relevant innovation. Although blockchain brings regulatory challenges to authorities, it creates opportunities for governments to improve the efficiency of public services and to fight corruption. As a promoter of technological innovation, governments should not only encourage other stakeholders to explore the potential of blockchain but also proactively develop use cases of blockchain for public services.

With regard to governance, the strategies adopted by the policymakers will influence the future development of blockchain. Regulators have to be mindful when making policies to set boundaries of the technology. They should seek an appropriate balance between fostering innovation of the distributed ledger technology and safeguarding the safety and security of market participants and the interests of the public as a whole (Ducas and Wilner 2017; Paech 2017). The regulations need to be so flexible and adaptive that it can evolve in parallel with the changes in new applications (UK Government Office for Science 2016).

When making rules to control operations in blockchain's digital world, apart from the classical legal code, policymakers could also consider the technical code (UK Government Office for Science 2016). Technical code here refers to software and protocols that are used to determine how programming language is coded. The technical code for blockchain is currently maintained and improved through private participants such as the Bitcoin Improvement Proposal of Bitcoin. The public sector can also be involved in the process of designing and maintaining technical code. For instance, the Internet TCP/IP was created by US government-funded projects. Through involving in developing technical code for blockchain, the public sector can influence the rules of blockchain with the same regulatory effects as legal code.

While China and Russia adopt a restrictive policy at present to ban ICO and cryptocurrency exchange, a majority of jurisdictions in the world such as Canada are employing a wait-and-see approach (European Securities and Markets Authority 2016; Ducas and Wilner 2017). Nevertheless, the above two strategies are both not encouraging and may push the innovators away to a more regulatory-friendly country (Ducas and Wilner 2017). In order to better utilise the potential of blockchain and minimise the identified risks at the same time, governments could consider a more facilitative approach to encourage pilot projects with a certain degree of restrictions. The Sandbox program adopted by the UK government is a good example. It provides a relatively relaxed environment where authorised organisations can test their innovations to a limited range of consumers for a limited duration while ensuring that appropriate safeguards are in place (UK Financial Conduct Authority 2017).

Table 5. Implications and recommendations to maritime stakeholders in blockchain adoption.

Maritime Stakeholders	Implications and Recommendations
Ship Operators	• Start with small projects and selective areas first • Graduate adoption in parallel with the development of regulatory framework and maturity of the technology • Proactively seek cooperation as blockchain cannot be so beneficial without reaching a critical mass
Terminal Operators	• Integrate blockchain with port community systems • Embed blockchain in port systems like smart grid to enhance automation in terminals
Classification Societies	• Be a blockchain knowledge centre and blockchain service provider in the industry • Leverage their expertise especially in setting up standards to assist in establishing blockchain standards in the industry
Equipment Manufacturers	• Monitor the developments of blockchain • Integrate blockchain technology with 3D printing for a smoother and more secure service
Technology Providers	• Focus on developing interoperable solutions to maritime organisations • Be in parallel with the development of the regulatory framework and technology.
Service Providers	• Proactively involve in developing industry standards of blockchain protocol • Make efforts to educate users because blockchain is in vain if few people use it • Be prepared with the low speed of blockchain diffusion in the industry
Government Agencies	• Combine legal and technical codes to govern the use of blockchain • Lead industrial cooperation by connecting different players to set up standards • Cooperate with international organisations and other jurisdictions to set up global regulatory principles • Revising its legal framework to encourage the use of blockchain in business

Source: Authors.

Blockchain innovation could be expensive especially for small and medium enterprises. It is necessary for governments to step in to make the innovation more accessible so that the whole society can improve evenly. Therefore, governments can consider providing incentive schemes such as providing innovation playground for companies to try. Other ways of encouraging blockchain for governments are to seek cooperation with international organisations and other jurisdictions to facilitate an establishment of global regulatory principles to enable wider adoption of blockchain (Ducas and Wilner 2017), as well as to bridge various industry players to participate.

Based on the above analysis, detailed implications and recommendations for different maritime stakeholders are provided in Table 5 for them to better capture the opportunities of blockchain and foster blockchain adoption.

7. Conclusion

Current research on blockchain applications in the maritime industry is scarce and mostly confined to a specific maritime sector. This paper consolidates and analyses the current and emerging blockchain applications from different maritime sectors with detailed reasoning of why blockchain is suitable for each use case. The results suggest that the ultimate goal of these applications is to achieve lean process via reducing paperwork, enhancing information sharing and automating processes. As such, a novel conceptual framework is developed to provide a holistic view of blockchain adoption in the industry by answering why blockchain can be applied in the industry, how it can be applied, and who are the major stakeholders in each use case. Based on the framework, future research directions are suggested around quantitative testing of suggested relationships between different dimensions of blockchain adoption, further investigation of the emerging trends of blockchain applications in the industry, quantitative analysis of blockchain's commercial impact and adoption time, and stakeholder analysis of blockchain adoption. Lastly, implications for organisations and governments are discussed and recommendations to various maritime stakeholders are provided.

The contributions of the paper are four-fold. Firstly, it develops a novel conceptual framework to systematically conceptualise blockchain adoptions in the maritime industry. It helps researchers and practitioners to converge their understanding of blockchain adoption in the industry and form a common basis and guide for future research. Moreover, this framework can be extended as a general tool for analysing the applications of a specific technology in a specific industry. Secondly, this paper is the first to consolidate the state-of-the-art of blockchain applications in the maritime industry. It assists stakeholders to better understand why and how blockchain can be applied in different maritime sectors and hence stimulates use case development in the industry. Thirdly, the implications and recommendations provided in the paper shed light to individual organisations on how to ride on the wave of blockchain smartly and to government agencies on how to better promote and govern blockchain innovation. Lastly, this study identifies ample future research opportunities and represents a research agenda for the field of blockchain adoption in the maritime industry.

Our study has some limitations. The study has captured the current major blockchain applications and emerging adoption trends in the maritime industry. However, with the continuing development of blockchain and the growing understanding of the technology in the industry, more use cases and other potential benefits and challenges of blockchain could arise and may not be included in the paper. Therefore, this study serves as a baseline for future deployment of blockchain in the maritime industry and the conceptual framework developed in the study creates value by guiding future research.

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