Blockchain conceptual framework in shipping and port management

Sanja Bauk

Durban University of Technology, Faculty of Applied Sciences, Maritime Studies Department (PO Box 1334, 70 Steve Biko Rd, Durban 4000, South Africa; emails: bsanjaster@gmail.com; sanjab@dut.ac.za)

Abstract: The purpose of this paper is to present a conceptual framework of blockchain (BC) deployment in maritime, which encompasses distributed relational databases (DBs), crypto-currency payment mechanisms, smart contracts, and tracking and tracing cargo capacities as main constructs. The core of proposed model is TradeLens platform. The document workflow management based on smart contracts, financial processes based on crypto-currencies and cargo tracking and tracing in close to real time based on Radio Frequency Identification (RFID) technology, Internet, satellite connections and back-end secured web oriented DBs are key dimensions of the proposed model. The stakeholders play the role of intermediaries in goods, accompanied data, and documents flows, including the supervision of the processes between end-nodes, i.e., suppliers and consumers, and they are involved into the model, as well. The paper identifies some strengthens and frailty of blockchain-based global maritime supply chain system, which includes both shipping and port management, and proposes some directions for further investigation in this domain.

Key words: blockchain (BC), maritime, framework, key constructs.

1. Introduction

Supply chains are among the largest and most complex systems in the business now-a-days. There are usually up to 30 or 35 independent entities involved, over a hundred people and 200 separate exchanges of information and documents created within end-to-end supply chain. As a robust system, it is inefficient in its current context [1]. Due to the World Economic Forum by reducing barriers within the international supply chain, which includes shipping and port management, global trade could increase by nearly 15%. This can enhance economics and create new employment opportunities. More precisely, reducing barriers in global trade for 5–20%, can increase worldwide trade volume by 10–15% and affect global gross domestic products (GDPs) by 3–5%, and in particular for individual developing countries GDPs by up to 15% [2]. Today information is exchanged in bilateral manner between shippers and either their suppliers or the transport providers. The information is often trapped in organizational internal data bases, which means that commonly there are two or more versions of what is going on within the supply chain. Consequently, cargo is often delayed and certainly, this is inefficient because cargo information is available at one part of the supply chain, but not at the other. This leads to challenges like both inefficiency and blind spots, which lead to gaps; gaps lead to delays; delays lead to increased costs for everybody involved. Additionally, the processes today are dominantly manual in nature. A lot of information is keyed, re-keyed, and all these is time consuming, inefficient, and it creates a lot of anomalies, exceptions, and each one of those have to be dealt with a timely fashion to keep the cargo fluidly moving from end to end.

Custom's clearance is a crucial issue, for instance. Custom's authorities around the world are trying to find better ways to assess risk at early stage and to look at shipments that are of concern to them or potential customer to avoid impeding global commerce. Obviously, current processes are time consuming and costly. Customs are also trying to prevent identity and other frauds. Therefore, early risk assessment is a key component.

Which kind of information are shared across global maritime supply chain? This information are mostly shipping and port management milestones. The information on: has a container be staffed; has the container be gated; what is the estimated time of arrival (ETA) of the container at the destination, and so on, are in fact shipping and port management milestones. However, it is more than that. It is also the documents in maritime, both structured (smart contracts) and unstructured (like PDFs, scans, images, etc.), by making them available to the participants along the supply chain. The documents need to change 'hands'. They need to be approved, updated, and available to build workflow using smart contracts, like 'smart' bill of lading, clearance, insurance, etc. Smart contracts are a powerful tool in terms of driving cross-organizational dataflow in maritime.

Regarding the actual processes in maritime being so manual in nature and because of the information islands, shipping and port management operations with cargo, customs, freight forwarders, carriers and consignees, take time; time costs and can lead to delays, and ultimately cargo delay, custom's clearance delay, and additional costs. The operations in shipping and port management are by nature complex and this restricts the ability for companies involved in supply chains to understand adequately when the cargo is going to be delivered. The companies have to have buffers in their supply chains. The costs and inefficiency are born by everybody in the supply chain, but most importantly by the shippers who ultimately pay the costs of inefficiency.

2. Blockchain in maritime framework

By taking into account all afore noted, we would like to propose a conceptual framework or blockchain model in maritime supply chain. Of course, our model is developed onto the information we found through desktop research. It is known that industry is in advanced position in comparison to academia when it comes to disruptive technologies like blockchain. We found the majority of information about TradeLens platform established between Maersk and IBM and therefore we put it in the center of our model. The basic explanations about this platform are given in *Section 3*. The explanations we found through the study are at high level of abstraction and this is the reason why we are retain at the same level in developing and presenting the model at this stage. TradeLens is based on protected distributed relational databases with secure Internet connection as data transfer and storage medium. It encompasses smart contracts, which are briefly presented in *Section 4*. Due to the available secondary sources, we found out that TradeLens provides tracking and tracing cargo (containers) in close to real time and that it seamlessly cooperates in this respect with road and rail modes of transportation. This segment of tracking and tracing cargo will not be discussed here, but the following references can give the readers at least the idea how this segment functions [3];[4];[5]. Distributed relational data basis are very well covered in the literature and they are not consequently in the focus of the article. The segment of the proposed conceptual model, which was interesting for us from the very basic, descriptive prospective is presented in *Section 5*, which reveals the basis of crypto-currency payment

mechanism. The proposed model encompasses all relevant stakeholders in shipping and port management whose roles are intertwined and who exchange mutually the same sets of documents.

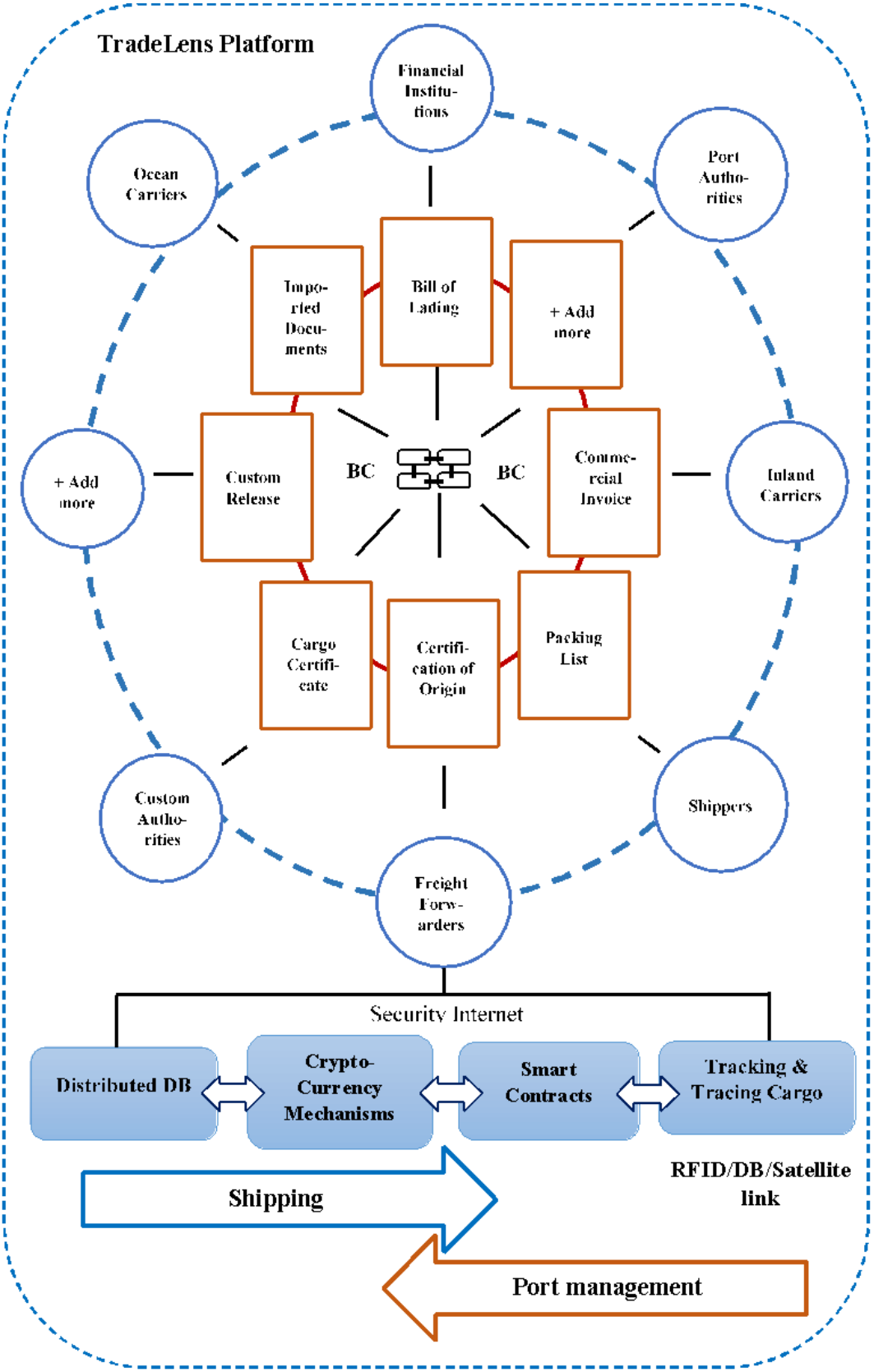

Figure 1. Blockchain conceptual framework in maritime supply chain (Source: Own).

We included into the model (Figure 1) as key actors: financial institutions, ocean carriers, port authorities, inland carriers, shippers, freight forwarders, and customs. When it comes to the documents they exchange, we listed: bill of lading (or waybill in maritime), commercial invoice, packing list, certification of origin, cargo certificate, custom release, and imported documents. However, TradeLens enhances opportunities for enlarging both sets of players and documents in the global maritime supply chains. In addition, these chains are logically extended to road and rail transportation modes, with the ultimate goal to reach the customers, i.e., consumers or products end-users at 'door-to-door' principle.

3. TradeLens platform features

TradeLens is a new business model in shipping and port management. It enables one-to-many connections for all the actors, all individuals that are involved in a global supply chain instead of bilateral connections. Everybody come together in a maritime industry neutral, open platform for every participant. Maersk, the world's largest international container shipping and logistics company and IBM the technology leader in blockchain came together to provide a new, open platform underpinned by blockchain to help unlock some of the opportunities for more efficient global supply chain. Maersk and IBM have a long history of working together, actually decades. In March 2017 these organizations collectively try to improve global trade through digitization. In January 2018, the two organizations launched early adapter program; trials began, and in August 2018, these formally launched the TradeLens limited availability platform, shared among 92 participants. In December 2018, TradeLens is commercially realized, along with 1.5 million events per day published to the platform [1]. Some of these events, which are recorded in the appropriate format by TradeLens are presented in Table 1. The platform can track 120+ unique consignment shipments, while 60+ network members are onboard or in a process of accessing. TradeLens supports 18+ unique, standardized, trade document types. Some of these documents are shown in Table 2. In February 2019, enhanced document sharing, permissions and notifications were released. The platform includes half a billion events on annual basis and this number grows with more and more network members. Twenty million containers of cargo information is in the system today, which is roughly 1/5 of global trade and it is growing. The platform involves numerous parties and systems: ocean carriers, ports and terminal operators, inland carriers, shippers, consignees, beneficiary cargo owners, freight forwarders, 3PLs, custom authorities, government agencies, financial and insurance services, transportation management systems, Port Community Systems (PCSs), supply chain validity systems, supply chair, manufacturers, retailers, etc. They all collaborate and share information. TradeLens provides them with comprehensive, real-time visibility and immutability across the end-to-end journey of shipment. In other words, data is available immediately, along with the single simplified view across all shipments. For instance, as a terminal operator publishes a piece of information about the fact that a container has been loaded onto a ship that becomes immediately available to everybody else in the supply chain. The idea is to build workflow based on smart contracts using chain code to derive cross-organizational workflow by excluding manual work.

Blockchain on which TradeLens is based, enables the trust in data that are available on the platform. It is an open and secured distributed database system, protected by encryption and decentralization mechanisms. Blockchain packs information in blocks on a shared ledger,

storing a synchronized copy of it on all the nodes (actors) in the network, while enhancing blockchain invariability [6]. The trust anchors, which are the blockchain special nodes, ensure through consensus algorithms that the information should be written on the platform as approved like valid. All information are auditable, verifiably and temper proof; so, as soon as a piece of data is published to the blockchain it cannot be edited. The only way to edit a document is to create a new version of the document. Consequently, all the documents are fully auditable. Additionally, cryptographic hash of the data is written to the blockchain, and this is a part of the supply chain. It is important to say that private data remain private. TradeLens as information sharing model allows ecosystem partners to have access to the information they should access and vice versa. The platform offers a high level of flexibility through application of RESTful APIs (Application Programming Interfaces), back-end ERP (Enterprise Resource Planning) and secured front-end web services.

Table 1. TradeLens standardized events (Source: [1]).

Actual	Estimated	Planned
Start container tracking	Documentation cutoff: Vessel ETD	Import documents approval
Start shipment tracking	VGM (Verified Gross Mass): Vessel ETD	Discharged from truck
Booking confirmation	Cargo cutoff: Vessel ETD	Loaded on vessel
Stuffing started	Rail ETD	Stuffing started
Vessel ATA	Rail ETA	Stuffing completed
Vessel ATD	Bill of Lading Available	Loading on vessel
Loaded on rail	Vessel ETD	Gate in
Rail ATD	Vessel ETA	Gate out
Rail ATA	Discharged from vessel	Packed container selected for inspection
Loaded on truck	Load on vessel	Packed container passed inspection
+Add more	Custom release	Cargo specific certificate approved
	+Add more	+Add more

In the middle of TradeLens solution there is the platform and blockchain behind it. Below the platform is the network. The network is not a physical network. It is set of entities that provide the data, including the data itself. The ocean carriers, ports, terminal operators, customs, shippers, inland transporters, etc., provide the data. On the top, above the platform are applications and services, i.e., RESTful APIs, back-end ERP, and secured web that enable people to exchange the information. These are based on open published industrial UN/CEFACT (United Nations Centre for Trade Facilitation and Electronic Business) standards that are defined at the platform level, so that third parties are allowed to build new value-added services and applications. This is the basic kind of model, through which TradeLens is moving forward as a paradigm shift in information sharing across the whole ecosystem.

Within TradeLens, there is sensor data and IoT (Internet of Things) for referring to the container number, electronic seal, and temperature inside it, for instance. All of that are part of the underlined data that is made available to the participants who need that data. This data are available in close to real time. There is a whole concept of seamless and permission data sharing model that is built on the base what your role is, i.e., are you terminal, ocean carrier, shipper, inland transporter, etc. The default permission model allows people to share information, so that information is made available to those who need it, but it is not available to those who should not see it.

TradeLens is of crucial importance whenever planned actions turn into unplanned. For instance, the ocean carrier's decision has implications not just for them but for all stakeholders further down the supply chain from customs brokers, port authorities and terminal operators to inland transporters and consignees. With TradeLens, changes to the shipment are reflected immediately allowing supply chain participants to coordinate actions tightly, delivering the consignee's inventory in time. TradeLens allows near-instant logistics adjustments so the disruptions are kept to a minimum. Global trade is an incredibly complex system, but TradeLens and blockchain create an industry-wide and innovative solution to alleviate this complexity and related impediments.

Table 2. TradeLens standardized documents (Source: [1]).

Document	Party
Import documentation approved	Customs House Broker
Customs release	Customs Authority
Cargo geography specific certificate approved	Customs House Broker
Bill of lading available	Beneficiary Cargo Owner (BCO)
Certificate of origin available	Beneficiary Cargo Owner (BCO)
Packaging list available	Beneficiary Cargo Owner (BCO)
Commercial invoice available	Beneficiary Cargo Owner (BCO)

4. Smart contract principle

Smart contracts are routines embedded into blockchain, which are activated when the preset conditions are fulfilled. They automate realization of the agreements, so that all participants can immediately become aware of the result, while avoiding involvement of any third party or time loss. [7]. Smart contracts work by following simple "if/when…then…" statements that are written into code on a blockchain. Or in other words, a smart contract presents the lines of code that are stored on a blockchain and automatically execute when predetermined terms and conditions are fulfilled [8]. A network of computers executes the actions when predetermined conditions have been met and verified. These actions could include releasing goods, funds, or confirmations in maritime supply chain. The blockchain is updated when the transaction is completed. This means the transaction cannot be changed, and only parties who have been granted permission can see the results. Blockchain network controls access. A smart contract may have as clauses as needed to satisfy involved parties, and that particular task should be accomplished successfully. In this regard, the actors must determine how transactions and their data are represented on the blockchain, i.e., they have to reach consensus on the "if/when...then…" rules that regulate the transactions, concern all possible exceptions, and define a way for overcoming the clashes. The smart contracts can be developed by programmers, but, the organizations that use blockchain for business can provide templates, web interfaces, and other online tools to simplify designing smart contracts. Key benefits of smart contracts are: speed, efficiency, accuracy, trust, transparency, and security (blockchain transaction records are encrypted, which makes them very hard to hack; plus, each record is connected to the previous and subsequent records on a distributed ledger, and hackers would have to alter the entire chain to change a single record). In maritime supply chain, sea waybill or bill of lading can be converted into a smart contract, while it requires an agreement between shipper and carrier, and/or any other relevant and permissioned parties to view the consignment, transport equipment, and documents, as permissions allow [9]. The benefits of such smart contract include: simplified transmission of shipping instructions; management of document status and versioning; faster submission of

shipping instructions for creation of final bill of lading; quick sharing of documents with all permissioned parties; including immutability, traceability, and auditability of the documents involved [10].

5. Blockchain crypto-currency payment mechanism principle

While bitcoin is a digital coin, i.e. money that is digital, blockchain (BC) is the technology that enables moving digital coins or assets from one entity to another within the network [11]. This section of the paper explains how BC solves the problem of money transfer at conceptual level. If entity A is sending money to entity B, usually this is done by a third trusted party, i.e. bank. The A gives order to the third party (bank) to make money transfer to B. Trusted party identifies B account and transvers money after taking some fees. This takes three or more days, if the transfer is done internationally. Blockchain transfers money without a third party, faster (immediately), and cheaper than a third party. Let us dive in into money transfer between A and B via BC. Firstly, we have to introduce 'open ledger' term. An open ledger is a chain of transactions among the nodes of the network, which is public and open to all participants. Everyone on the network can see where the money is, how much money each one has, and everyone can hypothetically decide whether an intended transaction is valid or not.

Example 1: Firstly, take a look to the concept of open ledger and how it can be implemented in BC. Let us assume that A has $15 and wants to move $5 to B. We are going to add this transaction to the ledger. Then, B wants to move $3 to C and we add this to the open ledger. The ledger is public and all nodes in the network can see and validate instantly the transactions if they are valid. Similarly, C can transfer $1 to D (Figure 2). However, if A wants now to move $15 to D, this transaction will not be approved, since A has only $10. Consequently, this transaction is unvalidated and it will not be added to the existing chain of valid transactions. This is simplified scenario with central, open ledger. If we assume that the ledger is distributed, it means that each node has a copy of the chain of synchronized transactions. This is more complex situation, and we are going to explain it through the following example.

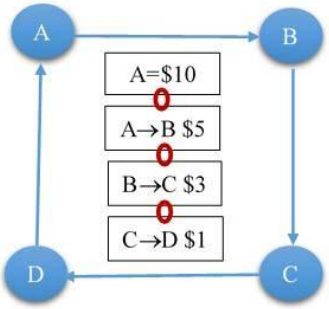

Figure 2. Centralized ledger (Source: Adapted from [11]).

Example 2: When ledger is distributed, each node holds the copy of the events that happened. In such a case, essentially we do not need centralized ledger. Now, we have to ensure that all copies of the ledger are synchronized and that all participants in the network see the same

copy of the ledger, i.e., same version of the chain of validated transactions. The question, which follows is: how nodes make and synchronize the ledger? The simplest way to answer this question is through an example. Let us assume that B wants to move to C $5 (Figure 3). The B is going to publish and broadcast this intention to the network. Everyone on the network will see immediately that B wants to move $5 to C. This is an unvalidated transaction. Next question is, how this intended transaction can be validated? In order to answer the question, we have to introduce the concept of 'miners'. Miners are specific nodes in the network that have capacity to compete mutually, in terms, which one will be the first to declare a transaction valid or not valid, and to put it into the ledger if it is valid. The first miner that did this got a financial reward. In this case 'bitcoin'. This means wining the competition and validating a new transaction. The winner has to fulfil two tasks:

T1: To discover whether B has enough money to make transaction, and

T2: To find a 'special key' that will enable this miner to lock the new transaction (if it is feasible) to the previous event (validated transaction) in the chain. In order to find the key miner needs computational power and time, since the key is random. The miner is repeatedly guessing keys, until it found the key that matches. If we assume, in our example, that D found the key, it will publish the key, so that other nodes can see it is a public and consequently updated oven ledger copies with a new, now validated transaction 'B moved $5 to C'. This means, A, B, and C will add automatically this transaction to their distributed ledger copies. In such a way, all ledger copies will become synchronized.

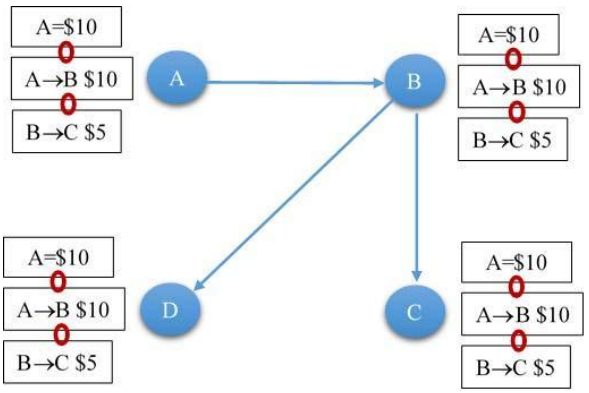

Figure 3. Distributed ledger (Source: Adapted from [11]).

At the operational level of blockchain-based maritime supply chain system, remains the question: who are the participants in such a network of financial transactions, and which nodes have the potential of miners? The answer depends on the particular case that might be analyzed in the particular setting and with a particular reason. Here is given just an idea or concept how blockchain based crypto-currency mechanism works in general. How it can be applied in a particular shipping or port management setting, within the blockchain-based supply chain, depends on a variety of conditions in which the observed system functions. The 300Cubits, ShipChain, and Prime Shipping Foundation (PSF) are initiatives that attempt to increase cryptocurrency deployment in maritime business [10]. However, there are still significant barriers and challenges to use blockchain and smart contracts in validating shipments and payments in maritime. The shipping industry increasingly faces cybersecurity threats, such as the NetPetya ransomware attack that affected Maersk in 2017, at a cost of over $200 million [12].

6. Blockchain pros and cons

Blockchain is a new, disruptive technology, with strong impact on global supply chain and maritime industry as its key component. It enables complex, controlled, distributed relational database transactions and consequently participants' easy communication and permissioned information share in near-real time. It allows cargo track and tracing along the entire supply chain in near-real time. Blockchain is a base for smart contracts in maritime as bill of loading, or waybill, for instance. It can incorporate smart payment mechanisms based on crypto-currency as 300Cubits, ShipChain, and Prime Shipping Foundation (PSF), instant payment systems. It enables early risk assessment and efficient interventions across supply chain when planned activities unexpectedly turned into unplanned ones, allowing prompt logistics adjustments, preventing delays and additional costs. Thanks to blockchain savings in administrative costs are considerable, approximately 15% of the value of the shipping goods in early testing [13].

However, there are some non-negligible impediments. The shipping industry is generally risk averse, tending not to be early adapter of new potentially risky technology [14];[15]. Some stakeholders in maritime want to keep their data secret, since "competition is fierce" and "a lot of industry actors are basically competing with the same service" [15]. In other words, some partners among the supply chain (including land rail and road transportation) consider information as a competitive resource and are unwilling to share them. Positional data might be used to track vessels by identifying port locations, fueling locations and routes [16]. This is the case with tracking dangerous and hazardous goods, pharmaceuticals, or food along supply chain. The use of blockchain does not guarantee that the information recorded in ledgers is correct and does not prevent tampering data prior to entering it into blockchain ledger, e.g., the contents of a container, fuel production, testing or combustion, and the like [17]. Due to huge amount of data and traffic generation, including data storage, blockchain requires a wideband like G5 or G6 [18], e.g., while the internet speed can be low when the working stage is offshore. Furthermore, it causes high-energy consumption [6]. Blockchain in the maritime sector indicates the potential to reduce transaction costs in a number of areas, including reducing the need for intermediaries such as brokers and courier services, and to reduce related financial expenses and energy costs. However, without taking into account the comparable costs of the overall investment and expenses associated with blockchain implementation and adoption, especially in developing environments [10];[19];[20]. Present level of awareness, knowledge, and expertise about blockchain is scarce among the stakeholders in maritime. Therefore, educational, training or capacity building programs are necessary at regulatory, administrative and operational levels. Higher level of standardization across the global supply chain is necessary. The Digital Container Shipping Association (DCSA) conducts efforts in this respect, but further, more extensive actions are necessary. In general, there is a hesitation by stakeholders in maritime sector to invest in blockchain systems in terms of technological integration, regulatory, organizational, and educational costs, since maritime sector traditionally relies on its legacy systems. There appears to be a gap between what practitioners in the blockchain area suggest and what has been a range of state-of-the-art approaches in the software engineering and information security research and practice [21]. Further, the major liner shipping companies are the most likely parties to benefit from blockchain given the complexity of their blockchains, diverse stakeholders' needs and huge requirement on financial resources [22]. This can put other potential actors in

the global supply chain at a disadvantage. The last but not the least, the basic attitude should be that technology, in this case blockchain on the top of global supply chain should improve the human condition, and not replace humans [23]. Therefore, human and ethical dimensions of blockchain technological development and more extensive deployment in maritime should not be neglected.

7. Conclusion

The paper presents blockchain conceptual framework based on TradeLens platform as a blockchain based solution for global maritime supply chain. TradeLens is an integrator business model, which provides the interface for connecting legacy systems in shipping and port management like Port State Control (PSC) and Enterprise Resource Planning (ERP), e.g., with blockchain. The descriptive model, which integrates different players in maritime transportation at the global scale, through many-to-many communication channels, controlled by consensus mechanisms used to reach agreements among all involved parties in the network about the correct state (update) of data on the platform, is presented. Each block in the chain contains a timestamp as well as hash value of the previous block. Smart cryptography mechanisms are used to ensure data immutability and trustworthy, but also to enable creation of smart contracts among the participants in the global marine trade and shipment schemes. Basic principles of cryptocurrency and payments without intermediary, i.e., without brokers and/or financial institutions has been presented on two simplified examples. Key benefits and challenges regarding further blockchain deployment in maritime are highlighted, too.

The paper is based on secondary literature sources, both "gray" and academic ones (EBSCO, Science Direct, Web of Science and IEEE Explore), but following research work in the field should be conducted in collaboration with maritime industry actors, both those who already use blockchain and those who are still indecisive about its implementation. Blockchain as a 'game changer' should be analyzed, in particular, in the context of developing economies, which struggle of lack of adequate (top) management and personnel skills, knowledge and expertise in the field, in addition to the lack of financial resources and 'fintech' innovation development actions. Security, safety, and ethical dimensions should be further and deeper investigate as well, along with the potential users readiness to introduce and adopt blockchain as a new integrated business model in maritime business and industry.

References

[1] White, M. *Shipping in the Age of Blockchain* [online]. TradeLens, 22 February 2019. [Accessed 20 June 2022]. Available at: <https://www.youtube.com/watch?v=Xwqo_fwPEJo&t=1925s>.

[2] World Economic Forum. *Enabling trade: valuing growth opportunities* [online]. Geneva: World Economic Forum, 2013. ISBN 978-92-95044-64-7. [Accessed 29 December 2021]. Available at: <https://www3.weforum.org/docs/WEF_SCT_EnablingTrade_Report_2013.pdf>.

[3] Liu, Y.; Tsai, H.C.; Shuler, J. Extending intervals for periodic leakage rate testing of radioactive material transportation packagings. *Packaging, Transport, Storage & Security of*

Radioactive Material [online]. 2011, vol. 22, no. 1, p. 27-34. [Accessed 20 June 2022]. Available at: <https://doi.org/10.1179/1746510910Y.0000000010>.

[4] Liu, Y.Y.; Craig, B.; Shuler, J. ARG-US remote monitoring systems for enhancing security of radioactive material. In: IAEA. *International Conference on the Security of Radioactive Material: The Way Forward for Prevention and Detection, Vienna, Austria, Dec. 3–7, 2018* [online]. IAEA-CN-269-319. [Accessed 20 June 2022]. Available at: <https://tuit.cat/ofv5n>.

[5] Bauk, S. Modelling radioactive materials tracking in sea transportation by RFID technology. *TransNav: The International Journal on Maritime Navigation and Safety of Sea Transportation* [online]. Poland: Faculty of Navigation Gdynia Maritime University. December 2020, vol.14, no.4, p. 1009-1014. eISSN 2083-6481. [Accessed 20 June 2022]. Available at: <https://doi.org/10.12716/1001.14.04.29>. Available at: <https://www.transnav.eu/Article_Modelling_Radioactive_Materials_Bauk,56,1089.html>.

[6] Vardai, Z. Top 5 blockchain trends for 2022 and beyond. In: *Forkast*. [online]. Hong Kong: Forkast, 31 December 2021. [Accessed 20 June 2022]. Available at: <https://forkast.news/top-5-blockchain-trends-with-lasting-impact/>.

[7] IBM. What are smart contracts on blockchain?. In: *IBM* [online]. [Accessed 1 January 2022]. Available at: <https://www.ibm.com/za-en/topics/smart-contracts>.

[8] Jensen, T.; Henningsson, S.; Hedman, J. How TradeLens delivers business value with blockchain technology. *MIS Quarterly Executive* [online]. 2019, vol. 18, no. 4, article 5, p. 221-243. [Accessed 20 June 2022]. Available at: <https://aisel.aisnet.org/misqe/vol18/iss4/5/>.

[9] IBM. *TradeLens documentation: actionable doc flows* [online]. IBM Corporation and GTD Solution Inc, 2020. [Accessed 20 June 2022]. Available at: <https://docs.tradelens.com/how_to/actionable_doc_flows/>.

[10] Green, E.H.; Carr, E.W.; Winebrake, J.J.; Corbett, J.J. *Blockchain technology and maritime shipping: an exploration of use cases in the U.S. maritime transportation sector.* [online]. U.S. Maritime Administration, June 2020. [Accessed 20 June 2022]. Available at: <https://www.maritime.dot.gov/sites/marad.dot.gov/files/2020-07/Blockchain%20Use%20Cases%20Final%20Report%20%2820200622%29.pdf>.

[11] Rubin, S. *What is Blockchain* [online]. 9 June 2016. [Accessed 20 June 2022]. Available at: <https://www.youtube.com/watch?v=93E_GzvpMA0&t=610s>.

[12] Mathews, L. NetPetya Ransomware attack cost shipping giant Maersk over $200 Million. In: Fo*rbes* [online]. Forbes Media LLC., 16 August 2017. [Accessed 20 June 2022]. Available at:

<https://www.forbes.com/sites/leemathews/2017/08/16/notpetya-ransomware-attack-cost-shipping-giant-maersk-over-200-million/?sh=5a59b48b4f9a>.

[13] Liu, J.; Zhang, H.; Zhen, L. Blockchain technology in maritime supply chains: applications, architecture and challenges. *International Journal of Production Research* [online]. 2021, vol. 59. [Accessed 20 June 2022]. Available at: <https://doi.org/10.1080/00207543.2021.1930239>.

[14] Gausdal, A.H.; Czachorowski, K.V.; Solesvik, M.V. Applying blockchain technology: evidence from Norwegian companies. *Sustainability* [online]. 2018, vol. 10, no. 6, 1985. eISSN 2071-1050. [Accessed 20 June 2022]. Available at: <https://doi.org/10.3390/su10061985>.

[15] Ytterstrom, J.; Lengerg, L. What role will blockchain play within the maritime shipping industry in five years? [online]. Master Thesis. Gothenberg: University of Gothenburg School of Business, Economics and Law, 2019. [Accessed 20 June 2022]. Available at: <https://pdfs.semanticscholar.org/b6d7/cf06c4853ef1745ab4dd12f65f3cc7f5bcb2.pdf>.

[16] Knirsch, F.; Unterweger, A.; Engel, D. Privacy-preserving blockchain-based electric vehicle charging with dynamic tariff decisions. *Computer Science Research and Development* [online]. 2018, vol. 33, p. 71-79. [Accessed 20 June 2022]. Available at: <https://doi.org/10.1007/s00450-017-0348-5>.

[17] Clift-Jennings A. (2019). Personal communication with Allison Clift-Jennings (Filament CEO), May 21, 2019. Cross ref.

[18] Bhattacharya, P.; Saraswat, D.; Dave, A.; Acharya, M.; Tanwar, S.; Sharma, G. Davidson, I.E. Coalition of 6G and blockchain in AR/VR space: challenges and future directions. *IEEE Access* [online]. 2021, vol. 9, p. 168455-84. ISSN 2169-3536. [Accessed 20 June 2022]. Available at: <https://doi.org/10.1109/ACCESS.2021.3136860>.

[19] Kapidani, N.; Bauk, S.; Davidson, I.E.A. Developing countries' concerns regarding blockchain adoption. *Journal of Marine Science and Engineering* [online]. 2021, vol. 9, no. 12, 1326. ISSN: 2077-1312 [Accessed 20 June 2022]. Available at: <https://doi.org/10.3390/jmse9121326>.

[20] Kapidani N., Bauk S., Davidson I.E.A. Deploying Blockchain in Maritime: Developing Environments' Concerns. *High Technology Letters*. 2021, vol. 27, no. 9, p. 942-951.

[21] Drljevic, N.; Aranda, D.A.; Stantchev, V. Perspectives on risks and standards that affect the requirements engineering of blockchain technology. *Computer Standards & Interfaces*, [online]. Elsevier, 2020, vol. 69, 103409. [Accessed 20 June 2022]. Available at: <https://doi.org/10.1016/j.csi.2019.103409>.

[22] Zhou, Y.; Soh, Y.S.; Loh, H.S.; Yuen, K.F. The key challenges and critical success factors of blockchain implementation: policy implications for Singapore's maritime industry.

Marine Policy [online]. Elsevier, December 2020, vol. 122, 104265. [Accessed 20 June 2022]. Available at: <https://doi.org/10.1016/j.marpol.2020.104265>.

[23] Burges, M. *Artificial Intelligence: how machine learning will shape the next decade*. London: Penguin Random House, 2021. ISBN 9781847943231.