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Johannes Schnelle, Meike Schröder and Wolfgang Kersten

Framework for the Adoption of Blockchain in Maritime Cold Chains

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Framework for the Adoption of Blockchain in Maritime Cold Chains

Johannes Schnelle [1], Meike Schröder [1] and Wolfgang Kersten[1]

1 – Hamburg University of Technology

Purpose: *This analysis aims to develop a conceptual framework for the adoption of blockchain-based solutions in maritime logistics. Using the application area of maritime cold chains, we examine which characteristics are crucial for the use of blockchain and which requirements need to be met for adoption.*

Methodology: *The method follows the approach of empirical data collection with expert interviews. From the interviews, a conceptual framework for the implementation of blockchain-based solutions into the maritime cold chain was developed using qualitative content analysis.*

Findings: *Within the interview study, we identified the potential for the use of blockchain in the maritime cold chain in providing an open and neutral platform in which data from different actors are securely integrated. The adoption of the technology requires considerations regarding economic evaluation, stakeholder integration, process development, data security, and legal compliance.*

Originality: *The implementation of blockchain in the maritime supply chain is a well-studied research area, but there remains a lack of the integration of data from the material flow such as sensor data. This research aims to fill this gap.*

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1 Introduction

The relevance of temperature-controlled global supply chains has strongly grown in recent years. This trend can be explained by globalization and the demand for offering various foodstuffs all year round (Fan, Behdani and Bloemhof-Ruwaard, 2020). Besides food, pharmaceutical products, or temperature-sensitive chemicals are transported under temperature-controlled conditions (Castelein, Geerlings and van Duin, 2020).

With the increasing complexity of the supply chains, it is becoming more important to obtain sufficient information in the supply chains to be able to react more quickly to risks (Scholten and Schilder, 2015; Schröder, et al., 2021). Due to the rapid perishability of the goods and susceptibility to temperatures, it is required to maintain the necessary environmental conditions, such as temperature and humidity level, as well as to avoid interruptions during the transport (Behdani, Fan and Bloemhof, 2019). Disruptions in the cold chain contribute significantly to the generation of food waste (Mercier, et al., 2017). A particular issue is the need to continuously maintain an appropriate cargo environment from the start to the destination of the cold chains (Filina and Filin, 2008; Bömer and Tadeu, 2014). In addition, customers and authorities are increasingly interested in receiving provenance knowledge to enhance the quality, safety, and sustainability of the products (Montecchi, Plangger and Etter, 2019).

An important role to ensure the ongoing material flow is the exchange of information enabling the coordination between the stakeholders (van der Horst and Langen, 2008). In the course of the digital transformation, information and communication technologies (ICT) such as cloud computing, artificial intelligence, or the Internet of Things are increasingly used in maritime logistics (Fruth and Teuteberg, 2017). While many processes are already digitized, there are still potentials to improve processes between and within companies through the integration of different data sources (Heilig, Lalla-Ruiz and Voß, 2017). Therefore, digital platforms are becoming increasingly important to facilitate collaboration and transparency in supply chains. For example, visibility platforms such as project44, Fourkites, or shippeo integrate various data sources to provide their customers better insights into their supply chain, allowing them to automate their processes (Behrend, 2022).

These platforms also integrate data from sensor devices in cold chains, which are collected by specialized monitoring providers such as Sensitech or Visilion via wireless sensor systems (Bruno, 2022). Another approach for monitoring temperature-controlled shipments is the concept of smart containers (Dittmer, et al., 2012). There are initiatives, like the remote container management (RCM) of the Danish ocean carrier Maersk. RCM allows the customer to monitor the shipment within a web-based portal in real-time (A.P. Moller Maersk).

Blockchain technology is seen as one approach to the secure integration of information flows in supply chains (Kshetri, 2018; Gurtu and Johny, 2019). While applications for the exchange of documents in maritime logistics or the end-to-end tracking of food or pharmaceutical products are well advanced, there is no conceptual link between these two domains.

This paper aims to fill this gap by providing a conceptual framework that incorporates the business value of blockchain technology with potential application areas in the maritime cold chain. Through this approach, we aim to answer the following research questions (RQ):

RQ1: What business value is seen for blockchain in maritime cold chains?

RQ2: What are potential application areas for blockchain in maritime cold chains?

RQ3: Which are crucial requirements for the adoption of blockchain in maritime cold chains?

The remainder of this paper is structured as follows: in section 2, we define the key characteristics of blockchain and review the related literature for blockchain adoption in supply chains, focusing on use cases in maritime logistics and cold chains. In section 3, the methodology to answer the research questions is introduced. Based on the interviews, the process value, application areas, and requirements for the adoption process of blockchain are elaborated on in section 4. These results are discussed in section 5. Finally, in section 6 we draw conclusions and limitations.

2 Background Literature

2.1 Blockchain Technology

Blockchain is characterized by a decentralized database that enables verified transactions, which are stored immutable (Hackius and Petersen, 2017; Chang, Iakovou and Shi, 2020). By providing smart contracts, which are in a sense shared program code between different organizations, it is possible to automate the process between different actors (Wang, et al., 2019). Consensus mechanisms, such as proof-of-work, proof-of-stake, or practical byzantine fault tolerance, ensure that transactions are valid and that all nodes maintain the same database (Casino, Dasaklis and Patsakis, 2019).

Blockchains can be distinguished into two basic types: public and private blockchains (Casino, Dasaklis and Patsakis, 2019). Public blockchains are characterized by the fact that anyone can send transactions and view the state of the database. In contrast, access to private blockchains is restricted by a central authority and only authorized users can read and send transactions. Another distinction is the access to the transaction validation. In permissionless blockchains, any node can join the network and verify transactions, while in permissioned blockchains transactions are verified by a set of predefined nodes (Nærland, et al., 2018). Applications using public permissionless blockchains are e.g. cryptocurrencies such as Bitcoin or Ethereum (Wust and Gervais, 2018). In maritime logistics, mainly permissioned blockchains are used, which offer advantages in terms of data protection and system performance (Munim, Duru and Hirata, 2021). In addition, using sidechains or storing information off-chain allows for increasing the confidentiality and exchange of huge data amounts, while only the hash of the transaction is stored on the main chain (Hepp, et al., 2018).

2.2 Blockchain in Supply Chains and Logistics

Research on the topic of blockchain in supply chain management can be found in the literature from around 2014/2015 (Casino, Dasaklis and Patsakis, 2019). The domain of maritime logistics is specifically addressed since 2018 (Munim, Duru and Hirata, 2021). The areas of application cover various aspects of SCM, such as tracking the origin of products, the exchange of documents, certification, or the integration of the internet of things (Hackius and Petersen, 2017; Kshetri, 2018). In the following section, an overview of the developments of blockchain in the context of maritime logistics and cold chains is given.

Due to the potential to increase trust, approaches for the usage of blockchain can in particular be found in the verification of luxury goods and sensitive goods such as food and pharmaceutical products (Wang, et al., 2019). For example, Tian (2016) presents a concept for a system in which the various process steps can be securely integrated with the help of blockchain and RFID to increase traceability.

The digitization of document exchange and the reduction of manual processes are particularly relevant in the context of maritime supply chains (Pu and Lam, 2021). A prominent example is TradeLens, a blockchain-based platform initiated by IBM and Maersk. TradeLens aims to provide a platform for the secure exchange of data and documents enabling shippers to gain end-to-end visibility of their supply chains (TradeLens, 2022). An important element of TradeLens is the digitization of trade documents such as the Bill of Lading (Nærland, et al., 2018; Chang, Iakovou and Shi, 2020). In addition to TradeLens, many other initiatives are aiming to digitize the Bill of Lading like WaveBL or CargoX (Bavassano, Ferrari and Tei, 2020).

A different concept is followed by the start-up T-Mining with the "Secure Container Release". This blockchain-based solution in the Port of Antwerp aims to increase the security of the container release (T-Mining, 2021). Previously, a pin was issued by the shipping line to the freight forwarder and the terminal operator for the release of the container. The freight forwarder passes this pin on to its contractors, which authorizes them to pick up the container at the terminal gate. Based on concepts of blockchain, self-sovereign identity, and privacy, T-Mining enables a more secure process and potential for more efficiency and automation. Hackius, Reimers and Kersten (2019) investigate a similar use case in the port of Hamburg. They found opportunities for blockchain in the unification of the information flow, the standardization of communication, and the increase of formal security.

For the integration of the Internet-of-Things, approaches can be found in particular in pharmaceutical supply chains (e.g., Bocek, et al., 2017; Fournier and Skarbovsky, 2019).

Blockchain could serve as a basis to simplify the complex process to reach compliance with legal requirements such as Good Distribution Practice (GDP). It also enables verification of the sensor unit without having to rely on a third party, which can be costly and time-consuming (Chanson, et al., 2019). One example of this application area is the eZTracker of the Singaporean pharmaceutical distributor Zuellig Pharma. Through the blockchain-based application, patients can verify whether the drug originates from an authorized source by scanning a QR code (eZTracker, 2022). As medical products such as vaccines need to be stored in temperature-controlled conditions, users are enabled to verify that the products are safe before being used.

In addition to the application areas and potentials, the literature also deals with barriers and challenges to the adoption of the technology. In particular, the high latency times for transactions and low storage capacity are seen as a challenge (Tian, 2016; Reyna, et al., 2018). By providing a transparent network, privacy is a challenge for the use of blockchain (Reyna, et al., 2018; Hackius, Reimers and Kersten, 2019; Papathanasiou, Cole and Murray, 2020). Besides technical barriers, barriers can also be found in the organizational area, both within and between companies (Saberi, et al., 2019). For example, the lack of knowledge and successful deployment examples is identified as a barrier to adoption (Papathanasiou, Cole and Murray, 2020; Zhou, et al., 2020). Another barrier can be found in the lack of technology readiness of many players, which is attributed to a low level of digitalization or the traditional character of the logistics industry (Papathanasiou, Cole and Murray, 2020; Balci and Surucu-Balci, 2021).

While the implementation of blockchain in maritime logistics and the use of the Internet-of-Things in supply chains have been explored, a conceptual link between these domains is missing. Jabbar and Bjørn (2018) show based on three use cases that the blockchain encounters an existing infrastructure when it is introduced into maritime logistics. Therefore, an adjustment is required for both, the configuration of the blockchain and the information system. As shown in Figure 1, the maritime cold chain consists of a complex network of public and private actors with different objectives (Fan, Behdani and Bloemhof-Ruwaard, 2020). These actors exchange trade documents, as well as planning and status information, via various forms of communication such as telephone, mail, email, or EDI (Jensen, Bjørn-Andersen and Vatrapu, 2014). Besides this information, real-time information for monitoring temperature and other environmental parameters is increasingly exchanged (Castelein, Geerlings and van Duin, 2020). Improving the exchange of information could increase efficiency in the supply chain to better utilize equipment, save resources and proactively monitor quality in real-time (Mercier, et al., 2017; Fan, Behdani and Bloemhof-Ruwaard, 2020).

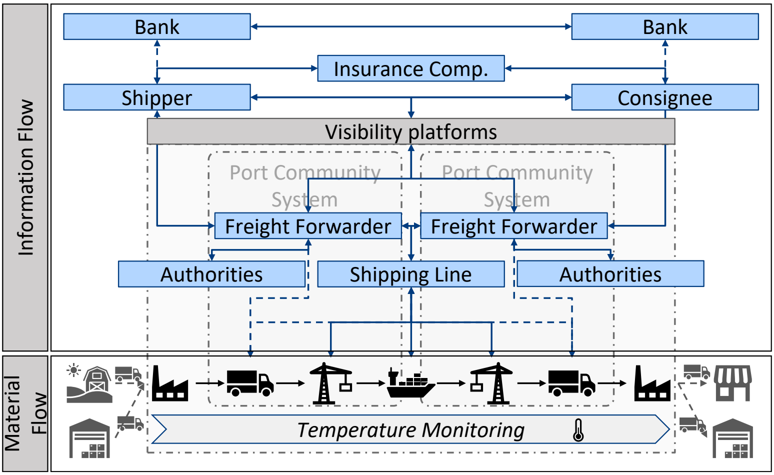

Figure 1: Key Stakeholders and Information Flow in Maritime Cold Chains (van Baalen, Zuidwijk and van Nunen, 2008; Behdani, Fan and Bloemhof, 2019; Fan, Behdani and Bloemhof-Ruwaard, 2020)

This study aims to develop an understanding of the existing information infrastructure in the maritime cold chain and how blockchain contributes to its further development by providing an overview of its application areas, opportunities, and requirements for adoption. However, the analysis will not be limited to how blockchain technology can be implemented, but also what general conditions need to be addressed to apply new ICT in the domain of maritime (cold) logistics.

3 Methodology

To develop a framework for the adoption of blockchain in the maritime cold chain, we conducted sixteen semi-structured interviews in two cycles. The interviewed experts were selected based on a combination of the criterion and purposeful random sampling (Patton, 2002). In particular, the aim was to include perspectives from the different functional areas of the maritime cold chain as shown in Table 1. Twelve interviews were conducted in German and four in the English language via telephone or video telephony due to the social distancing during the corona pandemic. The interviews lasted between 20 and 104 minutes, with an average of 60 minutes.

In the first interview cycle between July and September 2020, we selected particularly experts from the operational business to develop an understanding of the process and to derive the need for new ICT in maritime logistics. In the second interview cycle between December 2021 and April 2022, the focus was primarily set on understanding the adoption of blockchain in the logistics process. The ten interviewees in this cycle can therefore primarily be found in the areas of service providers for ICT and experts with previous experience in the implementation of blockchain-based projects.

Table 1: Demographics of the Interviewees

ID #	Organization Type	Expert Position
1	IT-Service Provider	Project Manager, Head of Business Development
2	Ocean Carrier	Sales Executive
3	Insurance Service Provider	Managing Director
4	Fruit Importer	Head of Quality Management
5	Logistics Consulting	Partner

ID #	Organization Type	Expert Position
6	Logistics Service Provider	Project Manager
7	IT-Service Provider	Freelancer
8	Insurance Service Provider	Head of Business Development
9	Electronics Producer	Head of Tracking-Division
10	Logistics Service Provider	Chief Technology Officer
11	IT-Service Provider	Chief Information Officer
12	IT-Service Provider	Head of Technology
13	IT-Service Provider	Managing Director
14	Electronics Producer	Head of Cloud Development
15	Pharma Producer	Head of Supply Chain
16	Terminal Operator	IT-Manager

To structure the interviews, an interview guideline was developed in advance. The aim was to understand on the one hand the drivers for the digitalization of the supply chain and on the other hand to understand the potential role of blockchain. For this purpose, the interviews were divided into two parts: in the first part, the current process in the cold chain was discussed to gain an understanding of the structure of the process, the involved stakeholders, and the challenges that occur during the cold chain. In the second section, opportunities, and challenges for the use of blockchain were discussed, and in which areas of the supply chain blockchain could be beneficial.

The interviews were recorded, transcribed, and analyzed in a qualitative content analysis according to the approach of Mayring (2010). For this purpose, codes were formed based on the transcripts, and codes with similar statements were grouped. In the next step, the codes were combined into more general codes and assigned to the three analytical categories of the value of the technology, application areas, and requirements.

4 Development of the Conceptual Framework

Based on the identified categories, we analyzed the (1) process value of blockchain which is summarized in Table 2, (2) application areas for blockchain in maritime cold chains as shown in Table 3, and (3) requirements that need to be considered for adoption as shown in Table 4.

4.1 Value of Blockchain

A key value of blockchain can be found in the integration of different information flows. The maritime supply chain consists of a complex ecosystem of actors, many of which maintain their own data systems. In addition, new data sources emerged in recent years such as temperature data generated by the use of "intelligent containers" or real-time temperature loggers (Jedermann, et al., 2014). Blockchain is seen by experts as a suitable solution to integrate these data with the document flow of the shipment, thus simplifying the direct assignment of information to a shipment

Table 2: Values of Blockchain for Maritime Supply Chains

Value	Elements	Interview Reference
Integration of information flows	Integration of information flows from several stakeholders	1, 2, 4, 5, 9, 10 (5)
	Enabler for standardization and participation	7, 11, 13 (3)

Value	Elements	Interview Reference
Increasing data security	Increase trust	7, 8, 9, 13, 14 (5)
	Increase data integrity and avoid manipulation	5, 7, 8, 11, 13, 14 (6)
Open and neutral network	Decentralized network without a gatekeeper	7, 12, 13, 16 (4)

This enables data consumers to retrieve information directly from the source without being transmitted via intermediaries, avoiding media breaks which increase the transmission time and are a potential source of errors. In addition, blockchain can be an enabler for the standardization of processes, as illustrated by expert #13 on the example of TradeLens in which blockchain "*is only [used] to authenticate documents*", but "*even without that, the system would be quite useful*", as this kind of standardization not only allows to standardize the system but also to standardize "*the structure of the process*" which enables the communication between the different systems in the industry.

Besides the integration of data sources from different stakeholders, blockchain can serve to ensure the integrity of the data. Blockchain appears as an application "*with the goal that you get data integrity, meaning reliable data points in an application area where many stakeholders come together who do not know each other respectively do not trust each other."* (Expert #8). This benefit is particularly useful in the financial domain but also to ensure the immutability and integrity of documents in supply chains.

A key potential for the implementation of blockchain in supply chains can be found in the ability to exchange data in an open and decentralized network. This is especially true for permissionless blockchains, such as Ethereum, in which every participant has the same rights and, according to expert #7, should work "*like the internet. Not owned by anybody.*" Blockchain-based solutions in logistics, however, are usually permissioned, so as in conventional systems, there is a gatekeeper. This contradicts the benefit that could be achieved with a blockchain, expert #16 going so far as to say, "*And if you can't get it to work in such a decentralized way, then the question is whether I need a blockchain at all.*"

4.2 Application Areas for Blockchain in Maritime Cold Chains

The exchange of documents plays a crucial role in maritime transportation (Jensen, Bjørn-Andersen and Vatrapu, 2014). For example, in food supply chains it is of particular importance that "*everything that has been used in terms of pesticides, [...] certification status on the subject of sustainable production CO2 [...], social responsibility [...]*" is documented and communicated in advance (expert #4). Besides product-specific documents, this includes transport-related documents such as the packing lists or the bill of lading. Missing or erroneous documents can result in problems at the points of transfer, delays in the registration process at customs, or failing acceptance at the receiver of the goods. Through its verifiability blockchain provides a basis for the digitalization of document exchange.

Table 3: Application Areas and the Contribution of Blockchain

Application Area	Contribution of Blockchain	Interview Reference
Documentation of the shipment lifecycle	Digitize document exchange	4, 6, 7, 9, 11, 13, 16 (7)
	Documentation of transport process	1, 2, 3, 5, 14, 16 (6)
Automation	Automation of information exchange	2, 3, 4, 8, 13 (5)
	Automation of financial flows	8, 10, 13, 15 (4)

Application Area	Contribution of Blockchain	Interview Reference
Data-driven decision making	Improve coordination in logistics	2, 4, 7 (3)
	Real-time information on deviations in the process	1, 2, 9, 12, 14, 15 (6)
	Support data-based decisions of customers	1, 2, 8, 9, 12, 15 (6)

For cold chains, reliable documentation is of particular importance when the cargo does not arrive in the ordered condition. Although the temperature is recorded during the intermodal transport, important information is often missing in the phases before and after shipment and is hardly standardized as shown by a statement of expert #3: "*This transparency, the fruit is hanging on the tree, the fruit is in the warehouse and [then] cooled and packed, that is [still a] gray area, there is a lot of information missing."* Multiple interviewees mentioned the potential of blockchain to consolidate different data sources in one place, as highlighted by expert #5: "*[With blockchain] you can define the risk transitions much more precisely and track them much more accurately. […] if you bring together the relevant parameters, it would be much easier. Today, it is still a bit of detective work*". By integrating all relevant information securely in one system, blockchain is found as a suitable approach for the documentation of the transport process. The integration also promotes the automation of the information exchange, so that documents for the clarification of claims are directly available, avoiding the time-consuming exchange of documents.

By integrating the different stakeholders, a blockchain-based platform could contribute to better coordinating the processes in the supply chains. With the integration of data from several steps of the supply chain, the quality-oriented approach 'first expire - first out' instead of 'first in - first out' could be implemented, as is already frequently discussed in the literature (e.g. Jedermann, et al., 2014). This approach could be for example used to prioritize discharge orders at the terminal as suggested by expert #4. If the data could be exchanged with the relevant stakeholders in real-time, there would be significant potential for improvement as „*If you could simply adjust the order at short notice [...], we would already be a huge step ahead* “.

4.3 Requirements for Adoption

4.3.1 Economic Evaluation

The adoption of new technological solutions is often associated with high costs (Tian, 2016; Tan and Sundarakani, 2021). The infrastructure for information sharing needs to be set up and surrounding processes must be digitized. Concerning the digitization in cold chains, investments are required for the sensing hardware and the setup of the communication infrastructure. Particularly for cargo with a relatively low monetary value, even small increases in cost can have a significant impact on the margins of the involved trading parties. This is described by expert #4 in the following way: “*[What we have to] make clear with fruit and vegetables, with such […] fast-moving consumer goods that we are more in a low-price segment. Costs naturally play a very large role here. [...] [If there is] no low-cost sensor technology, we do not get anywhere, because this option will not be used*." Therefore, it seems necessary to develop on the one hand solutions that are economically feasible for the potential users and on the other hand demonstrate which benefits they can derive from using the application to incentivize participation.

The implementation of blockchain technology seems even more difficult in the cold chain. Since customers usually engage the services of a supplier directly, there is no reason seen to question the data integrity. It seems in many cases questionable whether blockchain technology is the best solution to achieve the actual goal. The selection of the technology should therefore consider the actual needs of the users, instead of focusing on the implementation of a specific technology.

4.3.2 Stakeholder Integration

An important requirement for the successful adoption of blockchain can be found in the integration of the relevant stakeholders as organizations engaged in global supply chains are confronted with a multitude of platforms and interfaces when communicating with each other. This impedes collaboration in supply chains and increases the complexity as expert #2 points out: "*If you do not have enough data points, it may not even be enough for the customer to use that because they say: 'One of my important three customers is not mapped.'*" Therefore, it is necessary to create the conditions to enable the integration of all relevant stakeholders.

A major challenge lies in the fact that on the one hand, the organizations in the maritime industry are in intense competition with each other, but on the other hand, they are dependent on collaboration, as demonstrated by multiple consortia or vessel-sharing agreements between competitors (Elbert, Pontow and Benlian, 2017). The challenge is to get actors from different supply chains, as well as authorities from different countries onto one platform as described by expert #2: "*Bringing customs, veterinary authorities, government [...] all of them onto one platform is not that easy. Because you are not doing anything else than bringing all of them [together] and telling them: 'give me your data'. Everyone. And that is not easy. It does take time.*"

Besides the barrier posed by the competitive situation, the experts also claim that many stakeholders are reluctant to share information, as they fear providing too much transparency. Currently, a change towards increased transparency is ongoing, but this is still in its infancy. Expert #3 uses Maersk's remote container management as a positive example to illustrate that the idea of "*show[ing] [the customer] what is happening*" only works if "*the entire corporate philosophy is adapted that way*."

Table 4: Requirements for the Adoption of Blockchain

Category	Requirement	Interview Reference
Economic evaluation	Economically feasible solution	4, 5, 6, 7, 8, 13, 14, 15, 16 (9)
	Incentivize technology adoption	1, 8, 13, 14, 16 (5)

Category	Requirement	Interview Reference
	Problem and customer-oriented development	7, 8, 10, 11, 12, 13, 14, 16 (8)
Stakeholder integration	Integration of relevant stakeholders	1, 2, 3, 8, 10, 13, 14 (7)
	Change of corporate philosophy to enable transparency	1, 2, 3, 5, 7, 9, 11, 12, 14, 16 (10)
Process development	Digitization and verifiability of data capturing	4, 5, 6, 7, 8, 10, 11, 12, 13, 15 (10)
	Standardization of processes	11, 13, 16 (3)
	Adaption of processes	7, 11, 14, 16 (4)
Data security and legal compliance	End-to-end data integrity	7, 8, 14 (3)
	Tailored information flows	1, 2, 13 (3)
	Legal framework for technology adoption	5, 7, 11, 13 (4)

4.3.3 Process Development

As the verification of transactions on a blockchain only appears useful once the data has been recorded digitally and in a sufficient quality, it is required to digitize the processes to utilize the benefits of blockchain. For Expert #10, using the Blockchain requires first overcoming the manual input of data because "*as long as we're not at a level where all this data is [digitally] available, [as long as] integrating it does not do anything.*" An important aspect in cold chains is e.g., to ensure that the measurement of temperature is done correctly, as Expert #8 points out: "*If you measure nonsense, the blockchain does not help you either, because then you just verify a nonsense measuring point.*"

The implementation of new technology requires not only the digitization of the process but also adapting existing procedures. As expert #11 points out, "*blockchain [...] is a tool*." whose implementation is not just a technology project, but part of comprehensive change management, because "*what we are talking about is the improving business processes."*

Especially for a collaborative technology like blockchain, it is therefore required to standardize the process and ensure a mutual understanding of data. In maritime logistics, various initiatives and associations are working on standardizing the exchange of information. For example, UN/CEFACT and the industry association SMDG maintain the standards for the EDI messages. In addition, the World Customs Organization (WCO) manages a data model for communication with customs, and most recently the Digital Container Shipping Association (DCSA), an association of major shipping lines which aims to further promote the digitalization of maritime logistics through the development of standards (Schleyerbach and Mulder, 2021).

4.3.4 Data Security and Legal Compliance

Privacy requirements are one of the biggest concerns when implementing a blockchain-based network (Hackius, Reimers and Kersten, 2019). Generally, organizations strive to protect their business information as much as possible. Therefore, it should be ensured that the stakeholders only receive "*tailored information flows [...]. Not everyone gets to see everything.*" as stated by expert #2.

Besides ensuring the confidentiality of the shipment information, it is also required to protect information on business relationships as described by expert #6, "*the forwarder [...] lives from his network of carriers or ocean carriers to purchase at the best price and to sell that to the customer with a certain margin [...].*" If the service provider becomes known to the shippers, they could approach the service provider directly.

One challenge is that the blockchain only proves the data security of the data within the blockchain. For the data generated and processed outside the blockchain, the so-called Oracle problem arises or, as described by expert #14, the need for a "*chain of trust*": the data in the blockchain can only be regarded as secure if the integrity can be ensured from the source.

A technical solution must not only consider requirements regarding technical data security but ensure compliance with the legal environment. The challenge here can be that in many cases the legal basis for the use of the blockchain is not yet in place, such as with the electronic bill of lading. In addition, requirements regarding the location of data storage and data protection must be met, which can differ depending on the jurisdiction.

5 Discussion and Implications

Based on the analysis of the interviews, we could identify documentation, automation, and data-driven decision-making as three basic application areas which could benefit from the adoption of blockchain-based solutions. This is in line with the findings of Pu and Lam (2021) whose framework we were able to complement in particular with the elaboration of requirements for adoption, as well as the highlighting application areas and the business value of the blockchain, as shown in Figure 2. Tsiulin, et al. (2020) identified, another important application area in financial processes, which was only discussed as part of process automation in this study.

Contrary to our expectations, we found deviations in the benefits of the blockchain for the process. While the original expectation was that the sensor data itself in particular could be exchanged securely, it can be determined, at least for the maritime sector, that the stakeholders do not see the need for increased verifiability.

However, the potential for blockchain can be found in the secure integration of the document flow with the material flow data as an area of application. This enables the stakeholders to access the data via a single point of entry and thus, depending on the respective authorization, to obtain all relevant information from one place without having to build a time-consuming integration with each system they need to connect to.

The potential of the blockchain can only be utilized if the prerequisites in the technical and organizational areas are fulfilled. These are, in particular, the digitalization and standardization of processes, as well as the creation of awareness for data security. A major challenge here is the dependency on the partners in the supply chain. Even with smaller service providers, processes must be digitalized, and the corresponding technology must be available. As already noted by Chanson, et al. (2019) and Wang, et al. (2019), ensuring integrity from the source is one of the biggest challenges for integrating sensor data into the blockchain.

Establishing transparency along the supply chain was identified as one of the most important requirements. This is in line with the findings of Papathanasiou, Cole and Murray (2020), who in their study identified in particular the traditional culture and lack of will to change as a barrier to the use of blockchain in the maritime industry. Although a change already seems to be taking place here, as shown by the initiative of Maersk, there is still a lot of potentials to increase transparency.

However, establishing transparency should not be understood as simply disclosing data. It must be possible for the providers of data to control who receives the data and how it is used in the process. A frequently mentioned challenge during the study was the aspect that users are confronted with a large amount of data due to increasing transparency. Therefore, it seems necessary not only to provide the users with the data but also to provide them with additional means to avoid misinterpretation as far as possible.

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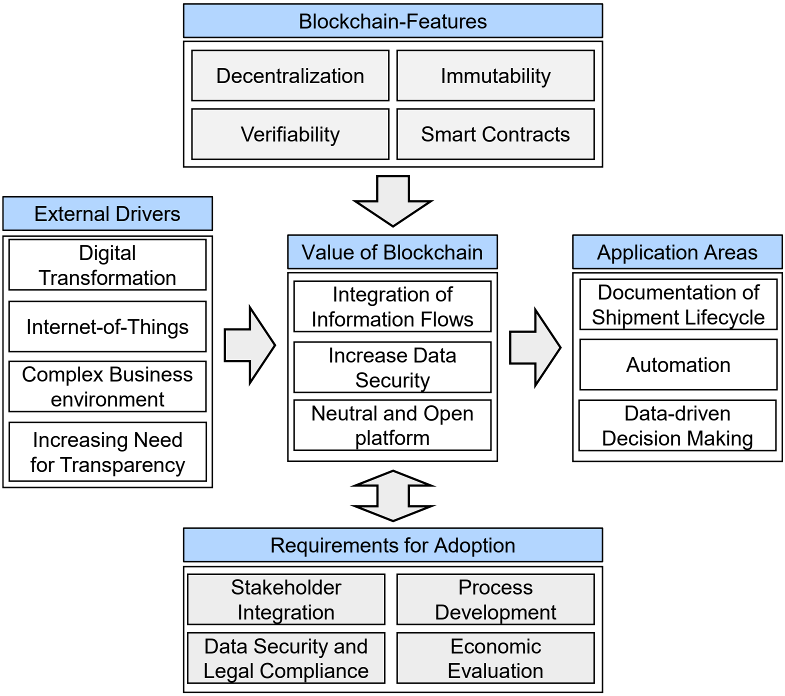

Figure 2: Conceptual framework for the Adoption of Blockchain in Maritime Cold Chains

Lastly, the implementation of blockchain-based applications should not only be seen as a technology project but rather as a tool to change processes. The development of technical applications should be oriented on the needs of the stakeholders and the underlying process behind them. Blockchain appears to be particularly suitable in cases where the stakeholders have little trust in each other, and the exchange of assets is involved. Although blockchain can be seen as the last level in the digitization of a process, the example of TradeLens shows that technologies such as blockchain are certainly suitable for driving the process of digitization and standardization in a complex network of actors, even if the role of blockchain in technical terms is rather minor.

6 Conclusions, Limitations, and Future Research Directions

This paper aimed to develop a conceptual framework for the adoption of blockchain in maritime logistics based on the use case of maritime cold chains. Therefore, we conducted sixteen semi-structured interviews which revealed three main application areas in the documentation of the shipment lifecycle, automation of information flows, and data-driven decision making. To implement blockchain into those application areas, especially requirements regarding the economic evaluation, stakeholder integration, adaption of the process, and data security need to be considered.

Thereby, blockchain should be seen less as technology and more as a concept to advance the digital transformation in supply chains. There is no doubt that blockchain offers advantages in secure integration, but the identified requirements demonstrate that most of the challenges are not exclusively related to the technology itself but rather to general issues in the governance of the information flow in supply chains.

This research is not without limitations. During data collection, it was not possible to separate the characteristics of the maritime cold chain from those of the general maritime supply chain. However, the boundary is becoming increasingly fluid for example Hapag-Lloyd announced to equip all its dry containers with sensor devices until 2023 (Johnson, 2022). We assume that the found requirements and steps for implementation also apply to these use cases as the stakeholders remain the same.

In addition, this research does not consider further or more general technology adoption models. To develop a more distinct understanding of the technology adoption process, it appears necessary to evaluate the findings of this research with other technology adoption processes.

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