Article
Application Prospects of Blockchain Technology to Support the Development of Interport Communities

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Abstract: A key aspect for the efficiency and security of maritime transport is linked to the associated information flows. The optimal management of maritime transport requires the sharing of data in real-time between the various participating organizations. Moreover, as supply chains become increasingly integrated, the connectivity of stakeholders must be ensured not only within the single port but also between ports. Blockchain could offer interesting opportunities in this regard and is believed to have a huge impact on the future of the digitization of the port and maritime industry. This document analyzes the state of art and practice of blockchain applications in the maritime industry and explores the application prospects and practical implications of blockchain for building an interport community. The paper uses SWOT analysis to address several research questions concerning the practical impacts and barriers related to the implementation of blockchain technology in port communities and develops a Proof of Concept (PoC) to concretely show how blockchain technology can be applied to roll-on roll-off transport and interport communities in real environments. In this regard, this study intends to contribute to the sector literature by providing a detailed framework that describes how to proceed to choose the correct blockchain scheme and implement the various management and operational aspects of an interport community by benefiting from the blockchain.

Keywords: blockchain; proof of concept; smart port; maritime transport; ro-ro transport; SWOT

1. Introduction

In the framework of the 4.0 revolution, digital transformation is of utmost importance for port and maritime logistics. Particularly, as crucial nodes in supply chains, seaports are required to constantly innovate and evolve in order to keep up with technological changes and remain competitive. Since the 1980s, the modernization of seaports has been shaped by digital innovation through three main stages of transformation [1]:

- First stage (1980s): transformation into paperless procedures (development of the first EDI-based port community system, development of maritime industry-specific UN/EDIFACT message standards, etc.);
- Second stage (1990s–2000s): transformation into automated procedures (application of automatic identification systems AIS, the introduction of radio-frequency identification for port operations, etc.);
- Third stage (2010s–onwards): transformation into digital procedures to improve responsiveness and decision making (sensors, mobile technologies, cloud computing, machine learning, etc.), and to support the ongoing interaction and connection between the actors involved.

Now, as supply chains become increasingly integrated and connected, it is essential to ensure the connectivity of stakeholders not only within the single port but also between the various nodes of the transport chain [2,3]. In particular, seaports are part of a complex
and information-intensive maritime supply chain that includes a set of organizations and operators that are connected and distributed [4]. However, several challenges have so far characterized and slowed down the development of shared digital solutions in the port community. Among the main ones, we can mention different levels of digital maturity between actors, missing standards, the reluctance of operators to participate and share information, etc. [1]. The recently much-debated blockchain technology could offer interesting opportunities in this regard and is believed to have a huge impact on the future of the digitization of port and maritime logistics [5].

Blockchain is defined as a digital ledger, decentralized and distributed, shared and agreed on a peer-to-peer network, where transactions are recorded and added in chronological order with the aim of creating permanent and tamper-proof records [6]. Whatever the sector of application, blockchain technology allows for more secure tracking of all types of transactions (money transactions, data transactions, information transactions, etc.), reducing delays, additional costs, and human errors [7]. Blockchain is designed to achieve decentralization, real-time peer-to-peer operation, anonymity, transparency, irreversibility, and integrity in a widely applicable manner [8]. In the context of shipping, blockchain technology is potentially a solution to the problem of distrust among players, as it does not rely on commercial third parties but on a network of peers [9]. It is also believed to have the potential to positively affect maritime processes [10] and accelerate the physical flow of goods [11].

The growing interest in blockchain technology in the shipping sector is also evidenced by the development of the related scientific literature. However, most of the available studies seem to focus primarily on the main trends and challenges [12–15], technical aspects [9,16,17], general opportunities [5,8,18,19], and impacts related to state-of-the-art technologies [10,20,21], while the practical implications of adopting blockchain solutions for specific port processes, as well as the actual repercussions for the different actors, seem to need further investigation, also considering that the technology is still new and immature [22]. A further observation is that, although some trials and blockchain pilot projects are already available in the maritime industry, they are mainly attributable to autonomous initiatives of industrial operators or single ports [23–27]. In this regard, it should be emphasized that as long as blockchain exists only in individual ports or in small groups of operators, its benefits will not be fully explored and exploited. In fact, in increasingly connected and integrated markets, the new era of digitization concerns not only the port’s ability to become smart but, above all, the ability to do so by connecting to larger networks.

In light of the above, this study intends to add to the existing literature by exploring the application prospects and practical implications of blockchain technology for the development of an interport community where different ports organized as a network can exchange information and data in a secure and effective way. Using five networked Tyrrhenian ports as an application case for the exchange of data and documents relating to interport logistic chains, this study develops a Proof of Concept (PoC) to concretely show how the blockchain technology can be applied to roll-on roll-off transport and port communities in real environments. The application considers the different players and activities involved in roll-on roll-off interport transport chains and investigates how they could take advantage of blockchain. A list of the main players of interest for this study, along with related activities and documents, is provided in Table 1.

It should be emphasized that, to the best of the authors’ knowledge, no available studies have been found that explore the practical implications of the application of blockchain technology for the establishment of an interport community composed of different ports. Nor that they propose a concrete model to show how blockchain can be applied to it or that they use software engineering techniques to develop such a system. Through this study, we try to provide insights on the topic by addressing the following research questions:

- What are the application prospects of blockchain technology to support the development of interport communities?
• How could the parties involved in a port community benefit from blockchain?
• What are the pros and cons of introducing blockchain in port communities?

Table 1. Players and activities in roll-on roll-off transport chains.

<table>
<thead>
<tr>
<th>Player(s)</th>
<th>Activities</th>
<th>Documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight forwarder, hauler, shipping company, terminal operator</td>
<td>Definition of the shipment</td>
<td>Bill of lading, contract</td>
</tr>
<tr>
<td>Freight forwarder, hauler, shipping company, terminal operator, port authority</td>
<td>Purchase of tickets, communications to the ports of departure, and arrival</td>
<td>Tickets, communications to ports</td>
</tr>
<tr>
<td>Hauler, port authority</td>
<td>Arrival of the truck at the port</td>
<td>Registration of arrival, possibly with photographic documentation</td>
</tr>
<tr>
<td>Terminal operator, hauler</td>
<td>Parking of the semi-trailer to be embarked</td>
<td>Parking registration</td>
</tr>
<tr>
<td>Terminal operator, shipping company, hauler (if accompanied cargo)</td>
<td>Ship loading and lashing</td>
<td>Load plan, demarcation document, ticket</td>
</tr>
<tr>
<td>Terminal operator, shipping company, port authority</td>
<td>Departure of the vessel</td>
<td>Ship documentation</td>
</tr>
<tr>
<td>Terminal operator, shipping company, port authority</td>
<td>Arrival of the vessel at the port of destination</td>
<td>Ship documentation</td>
</tr>
<tr>
<td>Terminal operator, shipping company, hauler (if accompanied cargo)</td>
<td>Unloading of the vessel</td>
<td>Unloading plan, demarcation document</td>
</tr>
<tr>
<td>Terminal operator</td>
<td>Parking of the semi-trailer disembarked</td>
<td>Parking registration</td>
</tr>
<tr>
<td>Hauler, port authority</td>
<td>Arrival of the truck at the port gate</td>
<td>Port access registration</td>
</tr>
<tr>
<td>Terminal operator, hauler</td>
<td>Pick-up of the semi-trailer</td>
<td>Port exit registration, possibly with photographic documentation</td>
</tr>
<tr>
<td>Freight forwarders, insurance companies, others</td>
<td>Transport damage complain</td>
<td>Complain and related documentation</td>
</tr>
<tr>
<td>Finance police, others</td>
<td>Control of the cargo</td>
<td>Report of the inspection</td>
</tr>
</tbody>
</table>

This work is relevant for what concerns the identification of all the stakeholders involved in interport logistics chains and the proposition of a cross-sectional SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to investigate the pros and cons of blockchain for the different subjects. Furthermore, the proposed Proof of Concept can act as a guiding tool for the realization of a working framework related to blockchain applications in the context of port logistics and supply chains.

To answer the research questions, the paper is structured as follows. After this introductory section, Section 2 presents the working methodology followed in this exploratory study. Section 3 introduces the blockchain technology and its properties and presents a state of the art and practice related to blockchain applications in the maritime sector. Using SWOT analysis, Section 4 summarizes the application prospects of blockchain to facilitate the secure exchange of information between the ports and the parties involved in an interport logistics chain. Section 5 briefly introduces the case study that originated the idea for this paper, while Section 6 reports the PoC we developed to concretely show how blockchain technology can be applied to roll-on roll-off traffic and port communities in real environments. Section 7 discusses the results of the study and presents some final critical reflections.
2. Methodology

This section briefly describes the working methodology followed in this exploratory study. The diagram in Figure 1 graphically depicts the methodology workflow adopted that led to the development of a PoC relating to the application of blockchain technology for an interport community.

![Methodology workflow diagram](image)

**Figure 1.** Methodology workflow. Source: authors.

This exploratory work began with the identification of the research goal, which is to explore the application prospects and practical implications of the blockchain for the construction of an interport community where different ports organized as a network can exchange information and data in a secure and effective way.

The learning process started with an analysis of the state-of-the-art in relation to blockchain technology and its specific applications to the context of port communities. This analysis was functional to the exploration of the practical implications of blockchain technology for the establishment of interport communities and useful to identify any previously developed concrete model that applied blockchain to interport communities.

The analysis of state-of-the-art was followed by the definition of the research gap to be filled. The latter concerns the lack of studies that specifically explore the practical implications of applying blockchain technology for the creation of interport communities, or that propose a concrete model to show how blockchain can be applied to interport communities to enable the various subjects belonging to different organizations and operating in different ports to exchange data and documents in a secure and certified way.

To bridge the identified research gap, a PoC was proposed to concretely show how blockchain technology can be applied to roll-on roll-off transport and interport communities.
in real environments. The PoC was developed using as an application case a prospective interport community composed of five roll-on roll-off ports in the upper Tyrrhenian Sea, and as a typical use case, the handling of a semi-trailer load that enters a port hub pulled by a vehicle crossing the port opening and arriving at a specific terminal where it is stationed in an assigned area for a certain time.

The ABCDE (Agile BlockChain Dapp Engineering) methodology was used for the analysis of the requirements functional to the development of the PoC.

3. State of the Art

The analysis of the state-of-the-art on blockchain in ports was built by following the triangulation research approach. The latter uses multiple and diverse data sources to develop a comprehensive understanding of complex phenomena. The proposed analysis includes both relevant academic work published on the topic and technical and industrial reports of sector experts.

This section is structured into two sub-parts. The first part recalls some basic notions and properties related to Smart Contracts and blockchain, which are useful for understanding how these can be applied in the context of maritime transport and interport communities. The second part collects and compares a set of selected use cases of blockchain technology in the maritime industry and presents a state of the art and practice related to blockchain applications in the maritime field.

3.1. Blockchain and Smart Contracts

The blockchain is a distributed and shared database whose past history is unalterable [28]. In public blockchains, the database is open to anyone who wants to contribute by installing the management software and a copy of it on their computer. In consortium or private blockchains, participation is subject to restrictions and conditions [29]. Whichever is the case, the mechanisms of the blockchain allow consensus among all nodes on the information stored so that no one can take control of it, not even generating fictitious nodes. Ultimately, blockchain can be seen as an automatic, non-centralized, cost-effective, and secure way to gain trust.

Transactions (and related information) are cryptographically signed and grouped into time-ordered blocks. The latter are cryptographically linked to the previous ones to create an unalterable chain of information. Transactions are signed by the sender address so that they belong to the owner of the private key associated with the public address on the blockchain. Transactions and blocks are both validated and added to the chain when a decentralized consensus is reached by the software—no one can be in control of the chain, and there is no central authority that gives or prohibits anyone from freely sending transactions or validating blocks. Figure 2 illustrates the main properties of the technology.

The blockchain can also be the infrastructure for running Smart Contracts. The latter can be defined as computerized protocols for executing transactions in which participants prove their identity and approval through their private key [28]. In input, they take digital signatures of participants and other information, while in output, they can transfer cryptocurrency amounts, record information, or activate other contracts. Smart Contracts make it possible to meet contractual conditions, minimize both intentional and accidental exceptions and minimize the need for trusted intermediaries. Once the contractual clauses are correctly inserted in the code of a Smart Contract and this is accepted by the contractors, the effects are no longer linked to their will or the action of intermediaries. The blockchain acts as the mechanism that guarantees the trust that the contractors place in the Smart Contract without the need to resort to a central authority. The introduction of Ethereum in 2015 led to a blockchain and a low-level language, along with various high-level and effectively usable languages (e.g., Solidity and Yul), to extensively code and execute Turing-complete Smart Contracts [30].
As with any new emerging technology, the blockchain comes with pros and cons. Among the former, the decentralized nature of the blockchain allows users to carry out online transactions at a fraction of the cost generally applied by traditional intermediaries.

Transactions on the blockchain are processed much faster than traditional value transfer systems, usually within minutes. With blockchain, time is saved by eliminating intermediaries, who have the role of checking that participants have corresponding registrations [11]. This feature is particularly significant when it comes to payments, which can take hours, days, or even weeks to complete.

Transactions made through a blockchain have no geographical limits. Furthermore, the elimination of intermediaries implies that transactions can cross national borders with less friction. There is also no need to trade or convert currencies. This makes the blockchain very suitable for carrying out international transactions and, in our particular case, for transactions in an international network of ports.

Payments made through the blockchain are irreversible: once the payment has been accepted, it can only be reversed by asking the recipient to retransmit the same amount with another transaction [28]. For the benefit of sellers, this feature prevents buyers from canceling their payments after purchasing a good or service. This reduces the risk of fraud and the cost of payment security. The irreversibility feature, however, is not only beneficial to sellers but also applies to other areas of application, including the transfer of ownership.

Privacy is also an important feature of the blockchain. Currently, to complete an e-commerce transaction or enter into a legally binding contract, participants must disclose their identity and other information to third parties. With the blockchain, it is not necessary to reveal sensitive personal information but only an address, which is an anonymous alphanumeric code. In addition to protecting the user’s privacy, blockchain transactions greatly reduce the risks of identity theft and fraud [5], common to other forms of transaction or payment, such as credit cards.

As for the cons, it is worth noting that in its current form, the blockchain requires above-average computer literacy to be used correctly [5,8]. This acts as a barrier to entry for those entities who want to use blockchain applications but do not know how to start. This can restrict access to new technologies for non-tech-savvy users and can expose them to risks of fraud. Furthermore, the decentralization of the blockchain means that there is no central resource to take care of the customers if they need assistance.

Although the Bitcoin blockchain has not been compromised so far, service providers (such as wallet service providers) are vulnerable to attack. Furthermore, transaction privacy,
seen as an advantage for many, is also a security concern. Not knowing the identity of the person on the other side of the transaction makes it difficult to resolve problems that may arise and can put you at risk of user fraud. Currently, access to blockchain applications is provided almost exclusively online. Physical touchpoints, such as Bitcoin ATMs and other physical service centers are scarce. Service providers are mostly new start-up companies with little reputation and no physical access points.

Finally, up to now, there are no well-defined laws or international agreements to legally regulate blockchain operations [8]. Much progress has been made in recent years, but there is still no international agreement on how to standardize blockchain applications. Current legislation is only limited to some financial applications of blockchain technology. To date, some Government agencies have studied consumer protection actions, trying not to hinder innovation, while others have imposed more restrictive regulations. This uncertain legislation, along with speculation, has brought other problems, such as the high volatility of the price of cryptocurrencies such as Bitcoin.

3.2. Blockchain for Smart Ports

The maritime industry is part of a complex and information-intensive supply chain that encompasses a set of organizations that are globally connected and distributed, including also other critical infrastructures that support world trade, such as transportation networks and port facilities [10]. The maritime industry has recently embarked on an important innovation process related to operational procedures and logistics, and one of the most promising areas concerns digitization. The latter may include the development of smart ships, smart fleets, and smart global logistics [8,24].

A crucial aspect of the efficiency and security of maritime transport is linked to the associated information flows. The optimal management of maritime transport requires the sharing of data in real time between the various participating organizations. This is particularly important during port logistics operations for better use of resources and infrastructures. Traditional ICT-based port logistics systems follow centralized architectures to host and process data and services. There is a redundancy of transaction information, and some processes are still very old and inefficient, requiring phone calls and a lot of paperwork. In addition, centralized logistics systems often fail to ensure secure and real-time access to data, operational visibility, and trust between participating organizations. However, the close coordination of the organizations participating in the logistic chain of the seaports is fundamental for the rationalization of the logistic planning processes. Efficient logistical planning and decision making also require a secure and transparent flow of different business documents between different stakeholders. For example, government authorities such as customs can delay or prevent a container from reaching its destination due to unsatisfactory commercial documentation (e.g., errors in bill of lading documents) [18]. The terminal’s efficient logistics planning is crucial to ensure optimized container loading and unloading. This is reflected in the reduction in the total downtime of autonomous or semi-autonomous cranes, the congestion rate of terminal traffic, and costs. In addition, automation of various port terminal functions via Internet of Things (IoT) and cloud computing can adequately increase the productivity of terminal operations. These operations can include [16,18,21,31,32]:

- The automation of the ship: automation in the naval sector involves both autonomous ships that use automation to manage repetitive routine tasks and remotely controlled ships that use automation to permit shore-based operators to monitor and control shipboard functions;
- Container management: for example, automated functionalities such as “arrival notice of export container” can enhance the customs control for export containers by using pre-notification systems and passing export declaration details electronically;
- Port intralogistics: automated port monitoring systems are used for the electronic processing of cargo data, container tracking within the port area, and managing ships’ stowage plan;
• Terminal gates: automated functionalities such as “reservation of arrival” or “cargo pick-up or delivery booking” can reduce turnaround times at the ports, reduce queuing at the port, and improve the planning of port activities.

In existing port automation systems, authorities leverage centralized mediation services to resolve commercial disputes between port logistics organizations [8,14,16]. Data records and transactions in centralized systems are vulnerable to modification, fraud, or deletion.

The studies by [33,34] showed that fleet and route planning problems, as well as delays, damage, theft of goods, or inadequate unloading of terminals and parking areas, are partly linked to the lack of cooperation between logistics operators, local authorities, and recipients of goods. The inefficient handling of goods and containers along the entire supply chain is a major problem in the industry. In particular, inefficient document management represents a serious burden for port management. According to [25,35], standard shipping involves dozens of parties (terminal operators, customs, shipping agents, port authorities, freight forwarders, etc.), with more than a hundred interactions between them [15]. Part of the problem is caused by the lack of information concerning the incoming transports, that is, related to notifications to parties along the supply chain regarding arrival, type of cargo, document checks, delays, and additional accompanying information [35]. In the event of additional customs inspections, which occur unpredictably and are poorly represented in digital format, the aforementioned delays greatly complicate delivery planning and subsequent payment processes [36]. Another problem is the lack of cargo security, in relation to both theft and mishaps, for example, when a company mistakenly takes another’s trailer or container. Commonly, a fair number of ports do not have verification tools to identify the driver’s permission to collect cargo. This creates uncertainties for both the recipient and the sender, also affecting the port’s image.

In such a context, blockchain technology can add value to port logistics and its digitization in different ways, influencing all logistical processes, from storage to delivery and payment, thus bringing strong innovation to a sector that is still antiquated in these aspects. In recent years, the maritime industry has experienced several promising blockchain-based applications. Figure 3 shows the different areas of the industry in which blockchain technology has been applied.

![Blockchain applications in the maritime industry.](image)

Figure 3. Blockchain applications in the maritime industry.
The remaining part of this paragraph collects and compares a set of selected use cases of blockchain technology in the maritime industry. The aim is to present a state of the art and practice related to blockchain applications in the maritime field and their impact on the development of maritime transport, also highlighting their advantages and possibilities of use.

The identification of the use cases started from the research of scientific articles on the subject. In particular, the “Google Scholar” search engine was used as it allows identifying not only published scientific articles, but also pre-prints, theses, books, and technical reports from all sectors of scientific and technological research. The keywords “port”, “blockchain”, and “logistics” were used to identify the main documents focused on the subject in order of citations. A further skimming was made based on the publication date; only the documents published in the last three years (from 2019 to December 2021) were selected to restrict the analysis to the most recent studies. Overall, 7310 documents were found (1660, 2350, and 3300 for the years 2019, 2020, and 2021, respectively). We then narrowed the search to the keywords “blockchain” and “port logistics”, finding 354 results (70, 116, and 168 for the years 2019–2021, respectively). This is still a large number, highlighting the interest and relevance that this topic is taking on more and more. We observed that the most cited among these results were papers focused on review or literature review on the subject, so we further narrowed the search by excluding the sentence “literature review”, finding 146 papers (34, 48, and 64 for years 2019–2021, respectively). Starting from the selected documents [7,19,37,38], a preliminary list of projects that use blockchain in the port area was built. Among these, the most targeted and for which sufficient documentation was available were finally selected. It is worth underlining that there are also other projects, in part already widely used around the world [37,38]; however, it has not been possible to find sufficient technical information to be able to deduce the minimum information required to be considered.

The analysis presented focuses thus on six case studies that use blockchain technology in various sectors of port logistics, for which sufficient information was available. Some of these projects are more mature while others are still in the start-up phase, but in any case, all are useful for having complete knowledge of the state-of-the-art. The information relating to the six case studies is summarized in Table 2, which reports the main characteristics of each case study examined: the name, the application area, the promoter, the subjects involved, the status of the project, the type of blockchain used, the main features provided, the strengths, and the weaknesses.

From the examples cited, it emerges that the blockchain technology in the port sector is usually used for two main purposes:
1. The digitization of documentation, commercial processes, and data exchange between participants;
2. Traceability to improve transparency on how goods are processed. Traceability itself serves three main purposes:
   - It can be used to increase transparency and build trust. This is done by providing the customers with detailed information about the blockchain-verified records concerning the steps a particular product has taken;
   - It can be used to prove the authenticity of products;
   - It can be used by large companies to quickly track and identify contaminated products, enabling companies to identify potential hazards and resolve them quickly.
Table 2. The blockchain in the port environment: use cases. Source: authors.

<table>
<thead>
<tr>
<th>Name</th>
<th>Scope</th>
<th>Promoter</th>
<th>Involved Subjects</th>
<th>Project Status</th>
<th>Blockchain</th>
<th>Functionalities</th>
<th>Main Strengths</th>
<th>Main Weaknesses</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-Mining</td>
<td>Container tracking</td>
<td>T-Mining (start-up)</td>
<td>Shipping carriers; Terminal operators; Barge operators</td>
<td>Advanced</td>
<td>Ethereum permissioned</td>
<td>Management and tracking of containers in the port (arrivals planning, authorized update of the status of a container, automatic validation of the container number)</td>
<td>No intermediary; Automatic updating of data; Automatic check of data validity; Time and cost reduction; Digitization of communication and documents; Increased interoperability using the same protocol; Prevents theft and human errors</td>
<td>Still in an experimental phase and focuses only on some aspects of international trade</td>
<td>[26]</td>
</tr>
<tr>
<td>Tradelens</td>
<td>Logistics and documentation management</td>
<td>Maersk and IBM</td>
<td>Ports; 3PL; Customs; Shippers; Port Operators; Maritime carriers; Control Authorities</td>
<td>Operational</td>
<td>Hyperledger Fabric</td>
<td>Digital platform for sharing documents and managing shipments, from origin to final destination</td>
<td>Real-time access to data, documents, and authorizations; Reduction in documentation and paperwork; Faster processing of information; Reduction in time, costs, and errors; Privacy and transparency; Standardization; Integration with IoT sensors</td>
<td>Poorly decentralized system. A proprietary system with lock-in risk</td>
<td>[39]</td>
</tr>
<tr>
<td>CargoX</td>
<td>Management of bills of lading</td>
<td>CargoX Ltd.</td>
<td>Carriers; Couriers; Terminal operators; Importers; Exporters</td>
<td>Advanced</td>
<td>Ethereum</td>
<td>Management of bills of lading using tokens and a dApp developed on the Ethereum blockchain</td>
<td>Open to all; No intermediary; Time and cost reduction; Security; Transparency; Verifiability of operations</td>
<td>Focused only on some aspects of international trade</td>
<td>[27]</td>
</tr>
<tr>
<td>Name</td>
<td>Scope</td>
<td>Promoter</td>
<td>Involved Subjects</td>
<td>Project Status</td>
<td>Blockchain</td>
<td>Functionalities</td>
<td>Main Strengths</td>
<td>Main Weaknesses</td>
<td>Ref.</td>
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<td>--------</td>
</tr>
<tr>
<td>Provenance</td>
<td>Product tracking</td>
<td>Provenance Ltd.</td>
<td>Producers; Carriers; Final customers; Certifiers;</td>
<td>Operational</td>
<td>Ethereum public</td>
<td>Tracking of product supply chains via blockchain, providing a unique digital passport readable via a QR code. Used in the port area for the management and tracking of loads and shipments</td>
<td>Transparency; Certification; Trust; Integration with QR readers; Digital passport</td>
<td>Focused only on some aspects of international trade</td>
<td>[40]</td>
</tr>
<tr>
<td>ShipChain</td>
<td>Logistics and Supply Chain</td>
<td>ShipChain Inc.</td>
<td>Carriers; Terminal operators; Barge operators</td>
<td>Failed</td>
<td>Ethereum</td>
<td>Set of logistics services that use blockchain technology for fight fraud and reduce losses in the shipping industry</td>
<td>Timely response to errors; Fight fraud; Security and transparency; System code available under an open-source license</td>
<td>The company has failed</td>
<td>[41]</td>
</tr>
<tr>
<td>CargoChain</td>
<td>Load management</td>
<td>Cargo Chain</td>
<td>Maritime carriers; Ports; 3PL; Customs; Shipper; Insurance companies</td>
<td>Evolving</td>
<td>Hyperledger Fabric</td>
<td>Load tracking along the chain. Simplification in the management, sharing, and ownership verification of the documents involved</td>
<td>Document process digitization; Transparency and trust; Off-chain sensitive data storage; Security; Integration with IoT devices</td>
<td>Still in an experimental phase and focuses only on some aspects of international trade</td>
<td>[42]</td>
</tr>
</tbody>
</table>
4. SWOT Analysis

In this section, we present the SWOT analysis to identify the implications of using blockchain technology in the context of port logistics. In particular, the four points of the SWOT analysis are:

- **Strengths**: internal factors; the attributions useful to achieve the objective; what you can use to your advantage;
- **Weaknesses**: internal factors; the harmful attributions to achieve the goal; what needs improvement;
- **Opportunity**: external factors; external conditions that are useful for achieving the goal; what you can benefit from;
- **Threats**: external factors; external conditions that could damage performance; what must be reduced.

Figure 4 shows a summary of the results, while the following subsections describe the four components of SWOT analysis in more detail.

![SWOT Analysis Diagram](chart)

**Figure 4.** SWOT analysis of using blockchain technology in port logistics. Source: authors.

4.1. **Strengths**

One of the main reasons for using blockchain technology is trust. In fact, the blockchain allows for a distributed, reliable and non-alterable database. The data recorded on the blockchain are transparent and immediately usable by authorized users, without geographical limits. Furthermore, these data can be encrypted in order to protect sensitive data and are safe and unalterable. This security and inalterability are made possible by the use of a double encryption mechanism [19], the first in the validation of transactions using a private key and the second in the concatenation of blocks. Finally, since all the writing operations on the Blockchain are managed through blockchain addresses that can only operate using the associated private key, all the operations can be traced directly to the owners of the address providing a transparent, integrated mechanism for identity management.

The concepts of trust, security, transparency, inalterability, and identity management, allowed by the use of the blockchain, are important in the context of ports. These are strengths that make it possible to increase the efficiency of shared processes, from planning to monitoring and coordination of operations, and also make it possible to identify responsibilities on the part of the actors involved, as well as the management of permits. Finally, all the actors involved in port logistics will benefit from this certainty of information not
only in real-time but also with regard to historical data for the retrospective analysis for process improvement.

An industry-specific example of strengths is the Port of Rotterdam, where blockchain has been used for implementing a decentralized electric power trading system with validation of transactions and management of digital identities in a pilot experiment led by the Blocklab company [43].

4.2. Weaknesses

Among the weaknesses encountered in the use of blockchain in the port sector, we highlight problems relating to governance, the lack of scalability, the reluctance on the part of the actors in adopting new technology, redundancy, and compliance with the GDPR. Indeed, the lack of a central authority can be an advantage but also a problem. In the context of port logistics, the various actors involved may have doubts about how and who is authorized to access the data (accessibility) and who owns the data (property) shared in the blockchain. Furthermore, in the case of a private blockchain solution, the question arises as to who is the neutral entity in charge of establishing the network rules and granting access authorization. Another known problem with blockchain technology is scalability, which is the limited ability of the Bitcoin network to handle large amounts of transaction data on its platform in a short amount of time, especially on a global scale [8]. The problem stems from the fact that the blocks in the Bitcoin blockchain are limited in size and frequency. While possible solutions are being explored, adopting the correct blockchain solution must take this issue into account so that adequate rates and transaction speeds must be ensured to meet logistical needs. As already mentioned, the adoption of this new technology can also be difficult due to technical and functional aspects. Both for the computing power necessary for large-scale implementation and because the interoperability between different actors involves the use of different languages and standards. As far as redundancy is concerned, although this involves an advantage in terms of security, it could be seen as a waste of resources by the actors involved. Finally, the information recorded on the blockchain, data, and transactions are always accessible to everyone and cannot be deleted, and this can cause problems with the EU regulation 2016/679 (GDPR). Even if the blockchain does not usually record cleartext data but their hash footprints, a specific strategy must be adopted from the beginning to take this problem into account.

4.3. Opportunities

This new technology allows leveraging new opportunities connected mainly to traceability, costs reduction through disintermediation, flow management, and coordination. Regarding the first, new blocks are added in an append-only fashion; thus, any event associated with logistic port operations can be temporally tracked by means of a sequence of temporally ordered blockchain transactions in a transparent electronic ledger [19]. Secondly, since the technology is decentralized, there is no need anymore of intermediation, and all operations are determined and governed by the rules written once and for all in smart contracts, removing human intervention and reducing costs [17]. Furthermore, the information flow is constant and is recorded in real time in blockchain blocks which are available for reading and auditing to all the actors involved, and all the sequential steps can easily be monitored with no additional costs, rendering it ideal for supply chain management [17]. Finally, all the records are immediately shared among involved actors so that the need for coordination among them is drastically reduced.

A specific example of opportunities in an industry-related context is provided by TradeLens [39], a platform jointly developed by IBM and Maersk that relies on blockchain for granting traceability of logistic transportation and shipping, also providing full transparency for container traffic [44].
4.4. Threats

As with every new technology, blockchain does not come without threats. One, in particular, affects privacy since the entire chain of transactions is stored and replicated in every local node participating in the network. This way, all participants can be targeted by hackers to exploit vulnerabilities and information leaks. It must also be noted that all the records are available to all participants so that if the information is not encrypted, it is immediately available to everyone [8, 45].

Some mitigating policies can be adopted to overcome such inconveniences, such as the adoption of external storage for preserving sensitive information, which can be linked to blockchain internal information with the adoption of access control policies.

Another issue related to the novelty is that the legal normative is not clear yet. There are no international agreements for defining legal or illegal usage of this technology, and its decentralized nature renders it very difficult to understand which legal systems are tight, constrained, or subjected to all the operations performed in a participating way from nodes that can be maintained in different world locations and nations [22]; the concept of the smart contract is fuzzy from a legal perspective.

A final issue is the storage capability of blockchains. This is usually quite limited with respect to, for example, cloud-based or other decentralized storage services. In fact, the ledger is made by identical copies maintained by all participating nodes, and this implies a redundant replication of the same information. Thus it is quite normal to rely on external frameworks for massive data storage that, by definition, do not guarantee the same security and immutability properties of the blockchain itself [46].

A practical example in the industry is given in [47], where the interaction of blockchain with other storage devices is illustrated.

5. Application Case

The idea for this study was born as part of a previous project, the so-called EasyLog project, which designed and built an ICT system for the exchange of operational data between five roll-on roll-off ports in the upper Tyrrhenian Sea [2, 48]. The five ports were Bastia in France, and Livorno, Olbia, Portoferraio and Savona in Italy (Figure 5).

![Figure 5. Location of the five ports involved in the application case. Source: authors.](image_url)

The project aimed to help overcome the lack of systemic vision that characterizes the maritime and port sector by proposing new shared and integrated technological solutions for the management of port gates and operations in intermodal roll-on roll-off transport chains. Ro-ro transport chains concern the transport of rolling cargo, i.e., cargo which is on wheels, such as trucks or trailers (but also containers if they are handled as swap bodies), and which can be rolled on and off the decks of a ship which has roll-on roll-off facilities.
The considered intermodal roll-on roll-off transport chains include at least one sea leg, one road leg, and a port call.

The EasyLog system was designed according to a modular structure in which each port had its own customized local module for managing gate-in gate-out operations, and the five local modules communicated with each other using a shared set of rules, the so-called Easylog connector, for data exchange and formatting.

Unlike existing ICT port systems, which are developed as standalone and closed systems, the Easylog system allows the secure and orderly exchange of information both in the single port and between the different ports in the network, thus improving the efficiency, reliability, and security of the broader maritime transport chain. Furthermore, through a modular structure that guarantees the autonomy of individual local systems, the Easylog system allows overcoming the barriers (a.o., different levels of digital maturity between the actors involved or missing standards) that typically hinder the adoption of shared ICT solutions in the maritime industry.

The field tests carried out at the five ports in May 2021 demonstrated the high operational potential of the Easylog system and its effective applicability to the logistic-port context. However, despite the important innovation introduced, the EasyLog system still has several limitations:

- It does not include all the actors involved in the interport logistics chain;
- It concerns only limited operational information related to gate operations but no sensitive data;
- Its process phases are not systematically linked between the stakeholders.

These limitations leave some room for improvements that blockchain technology can potentially achieve. Figure 6 illustrates a simplified flow diagram relating to the diverse activities and related information flows and operators, which could potentially take advantage of blockchain to create an interport community that connects two ports.

![Figure 6. Flow diagram of processes in a roll-on roll-off interport logistics chain. Source: [48].](image-url)
In order to demonstrate the basic operations and application prospects of blockchain technology in a roll-on roll-off interport community like Easylog, we have developed an ad hoc PoC whose features are detailed in the next section.

6. Proof of Concept

In this section, we report a Proof of Concept (PoC) to concretely show how blockchain technology can be applied to roll-on roll-off traffic in real environments. To devise the PoC, we used a testnet blockchain (see below) that supports Ethereum technology. The advantages of such an approach are:

- The most widespread technology currently in the world is used to deploy Smart Contracts;
- Costs and times of access to the infrastructure are reduced;
- No need to implement and maintain a node;
- Capability to operate with an architecture of Smart contracts and Dapp that would work in the same way also in a hypothetical blockchain prepared by the Port Authorities and other actors involved in the future, providing added value to the PoC in case of transfer of the implementation to another blockchain.

A testnet blockchain is a structure made up of blockchain nodes that communicate with each other using the same protocols and the same software as a public or private blockchain, but that do so voluntarily and free of charge in order to provide support for the experimentation, research and testing of software projects working on blockchain technology. In particular, transactions are activated using a cryptocurrency that has no commercial value and is therefore provided free of charge to the wallet of any user who requests it (albeit with limitations to avoid “Denial of Service” attacks). Response times can sometimes be long, as these structures are exploited by many users worldwide, but there are different options and testnets with different characteristics and performance, in particular with regard to response times. Public blockchain explorers also operate on testnets. Testnets do not guarantee (nor could they) the long-term retention of information, but in practice, they do: for example, the “Kovan” testnet maintains blocks dating back to 2017. The active and internationally available testnets are Görli, Kovan, Rinkeby, and Ropsten. A testnet that supports Ethereum technology and that has good response times, in particular with regard to experimentation for a Proof of Concept, is that of Ropsten, which we will use for the deployment of the Smart Contract.

We present as a typical use case of the Easylog system, the object of the proposed PoC, the handling of a semi-trailer load that enters a port hub pulled by a vehicle crossing the port opening and arriving at a specific terminal where it is stationed in an assigned area for a certain time. Upon crossing the gate, the license plate of the vehicle and that of the trailer and the documents of the driver and of the load are detected; upon arrival at the terminal, the two plates are registered for further confirmation, verifying that they are already among the plates registered at the port entrance, and a photo is taken to document the status of the trailer. At the appointed time, the trailer gets on the roll-on roll-off ship, and after lashing, the license plate is recorded again with verification that it already exists among the plates that entered the terminal.

Upon arrival, the reverse procedure is followed, recording the unloading of the semi-trailer and its parking in the parking area of the terminal, the collection by the motor vehicle entering to collect it, and the exit from the port.

Note that the same process can be applied to the transit of a truck, possibly with a trailer. The only difference is that the parking in the terminal area is much shorter and precedes the immediate boarding of the ship or the exit from the port of arrival.

6.1. ABCDE Method

For the analysis of the requirements, we will use the ABCDE (Agile BlockChain Dapp Engineering) method, developed at the Department of Mathematics and Computer Science of the University of Cagliari [29].

This method consists of the following steps:
1. Define the purpose of the system in a short sentence;
2. Identify the actors, meaning the parties involved, according to their specific interaction with the system;
3. Define the functional requirements in terms of “User Stories”; short descriptions of the interactions of the various actors with the system;
4. Divide the analysis into two parts:
   4.1. Requirements and functionalities of smart contracts running on the blockchain;
   4.2. Requirements and functionality of apps that interact with the blockchain;
5. Integration of the two systems, testing, and installation of the complete system.

The method involves development with an agile and, therefore incremental-iterative approach, creating a subset of the User Stories at each iteration. The various phases of the analysis and design carried out will be detailed below.

6.2. Purpose of the System

In a single sentence, the purpose of the system, to always keep in mind during analysis and development, is: “To develop a simple Dapp system to track and certify transport movements and documents within a community management system cross-border interport”.

6.3. Actors

System users are profiled according to the following categories:

1. Input-only via mobile terminal or dedicated hardware: operational user who works through the app (e.g., port personnel at the entrance gates who detect vehicle license plates).
2. Only remote input via a web interface: operative user who works via PC or, in any case, a web interface (e.g., registered haulier who pre-loads/integrates data relating to his transport).
3. Complete data management: operational supervisor user who can intervene to modify/integrate the data already written in the system.
4. Administrator user: user for profile management, system configuration, and parameterization.

In the system that creates the PoC, the types of actors identified are summarized in Table 3. For each actor, in the table, we specify a descriptive name, an acronym that we will use in the following, and a description of his role.

<table>
<thead>
<tr>
<th>Actor</th>
<th>Acronym</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Operative User/Security Controller</td>
<td>UOS</td>
<td>Port personnel who detect license plates or other data relating to trucks. Enter related data using specialized hardware (IoT) or manually; some data may already be loaded/pre-filled.</td>
</tr>
<tr>
<td>Remote Operational User</td>
<td>UOR</td>
<td>Registered user who enters, via PC, tablet, smartphone or other, the data relating to a transport, even prior to the actual departure.</td>
</tr>
<tr>
<td>Supervisor User</td>
<td>US</td>
<td>It has the task/possibility of modifying or integrating data already entered by others, obviously through correction operations, never cancellation or direct modification. Typically, they will be data written via smart contracts.</td>
</tr>
<tr>
<td>Administrator</td>
<td>AMM</td>
<td>The system administrator. Can manage user accounts and permissions. Therefore it should be the owner of the SCs that manages the read and write operations. It can add in the SC the addresses of the users authorized to carry out the various operations.</td>
</tr>
</tbody>
</table>

The actual actors involved in the PoC under analysis are shown in Table 4. Note that the second column shows the type of actor, with reference to those outlined in Table 3.
### Table 4. Actors of the Easylog PoC.

<table>
<thead>
<tr>
<th>Actor</th>
<th>Type</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Administrator</td>
<td>AMM</td>
<td>The system administrator of the EasyLog project enabled to initialization of the system.</td>
</tr>
<tr>
<td>Gate guardian</td>
<td>UOS</td>
<td>Records the entrances and exits of vehicles from the port.</td>
</tr>
<tr>
<td>Yard operator</td>
<td>UOS</td>
<td>Records the arrival at the vehicle terminal, both in departure and in arrival after disembarkation, with photographic documentation of the state of the vehicle.</td>
</tr>
<tr>
<td>Rizador</td>
<td>UOS</td>
<td>Records the embarkation and lashing of vehicles on the ship and disembarkation of vehicles arriving from the sea.</td>
</tr>
<tr>
<td>Port Authority Operator</td>
<td>UOR</td>
<td>Records ship departures and arrivals. It can possibly correct data and query the system.</td>
</tr>
</tbody>
</table>

6.4. Definition of the Requirements in Terms of User Stories

The functionalities of the PoC system to be implemented are defined in terms of User Stories (US). Each US has a goal, a descriptive name, and one or more actors associated. For this PoC, the relationships between actors and USs are very simple because each actor is involved in only one US. To ease the reading and understanding, these functionalities are outlined in Table 5. As can be seen, it is a simplified system, but it manages and tracks all the main events of the movement of cargo from one port to another.

### Table 5. User Stories of the PoC.

<table>
<thead>
<tr>
<th>Actors</th>
<th>Name</th>
<th>User Story</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate guardian</td>
<td>Port entrance</td>
<td>As a port operator, I want to register the number plates and tickets of the vehicles that cross the entrance gate.</td>
</tr>
<tr>
<td>Gate guardian</td>
<td>Port exit</td>
<td>As a port operator, I want to register the number plates of the vehicles that cross the exit gate.</td>
</tr>
<tr>
<td>Yard operator</td>
<td>Terminal parking</td>
<td>As a port operator, I want to record the arrival of a vehicle in the terminal yard, together with its photos, to highlight its status.</td>
</tr>
<tr>
<td>Yard operator</td>
<td>Terminal exit</td>
<td>As a port operator, I want to record the departure from the terminal yard of a vehicle leaving the port, together with its photos, to highlight its status.</td>
</tr>
<tr>
<td>Rizador</td>
<td>Boarding</td>
<td>As a port operator, I want to record the event of boarding a vehicle and its securing in the hold.</td>
</tr>
<tr>
<td>Rizador</td>
<td>Disembarkation</td>
<td>As a port operator, I want to record the event of a vehicle leaving the ship and its arrival at the terminal.</td>
</tr>
<tr>
<td>Port Authority Operator</td>
<td>Ship departure</td>
<td>As a Port Authority, I want to register the departure of a ship heading for another port.</td>
</tr>
<tr>
<td>Port Authority Operator</td>
<td>Ship arrival</td>
<td>As a Port Authority, I want to register the arrival of a ship from another port.</td>
</tr>
<tr>
<td>Port Authority Operator</td>
<td>Data verification</td>
<td>As a Port Authority, I want to verify the transport data relating to my port.</td>
</tr>
<tr>
<td>Administrator</td>
<td>System initialization</td>
<td>As a system administrator, I want to initialize the system by entering the port data.</td>
</tr>
<tr>
<td>Administrator</td>
<td>User Enabling</td>
<td>As a system administrator, I want to enable the various port actors.</td>
</tr>
</tbody>
</table>

Figure 7 shows the diagram of the possible states of a vehicle in transit between two ports, as deduced from the User Stories.
Table 5. User Stories of the PoC.

<table>
<thead>
<tr>
<th>Actors</th>
<th>Name</th>
<th>User Story</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate guardian</td>
<td>Port entrance</td>
<td>As a port operator, I want to register the number plates and tickets of the vehicles that cross the entrance gate.</td>
</tr>
<tr>
<td>Gate guardian</td>
<td>Port exit</td>
<td>As a port operator, I want to register the number plates of the vehicles that cross the exit gate.</td>
</tr>
<tr>
<td>Yard operator</td>
<td>Terminal parking</td>
<td>As a port operator, I want to record the arrival of a vehicle in the terminal yard, together with its photos, to highlight its status.</td>
</tr>
<tr>
<td>Yard operator</td>
<td>Terminal exit</td>
<td>As a port operator, I want to record the departure from the terminal yard of a vehicle leaving the port, together with its photos, to highlight its status.</td>
</tr>
<tr>
<td>Riza dor</td>
<td>Boarding</td>
<td>As a port operator, I want to record the event of boarding a vehicle and its securing in the hold.</td>
</tr>
<tr>
<td>Rizador</td>
<td>Disembarkation</td>
<td>As a port operator, I want to record the event of a vehicle leaving the ship and its arrival at the terminal.</td>
</tr>
<tr>
<td>Port Authority Operator</td>
<td>Ship departure</td>
<td>As a Port Authority, I want to register the departure of a ship heading for another port.</td>
</tr>
<tr>
<td>Port Authority Operator</td>
<td>Ship arrival</td>
<td>As a Port Authority, I want to register the arrival of a ship from another port.</td>
</tr>
<tr>
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<td>Data verification</td>
<td>As a Port Authority, I want to verify the transport data relating to my port.</td>
</tr>
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<td>System initialization</td>
<td>As a system administrator, I want to initialize the system by entering the port data.</td>
</tr>
<tr>
<td>Administrator</td>
<td>User Enabling</td>
<td>As a system administrator, I want to enable the various port actors.</td>
</tr>
</tbody>
</table>

Figure 7. UML state diagram with the states of a vehicle transported between two ports.

6.4.1. Data Specification

In order to better understand and design the system, it is necessary to identify data. The minimum data of interest to be recorded for each event are:

- Vehicle plates: nationality plate and actual number plate of the vehicle, and of the semi-trailer or trailer (null if it is a truck without a trailer);
- Date-Time detection;
- Place of detection (LOCODE + Local code);
- Location within the same node: “gate in/gate out”, “terminal yard”, “ship embarkation/disembarkation”).

The data relating to maritime races are:

- Port of departure;
- Port of arrival;
- Day and time of scheduled departure;
- Estimated day and time of arrival;
- Name of the ship;
- IMO (International Maritime Organization) ship code;
- Company;
- Trip code (generated by the system).

The data relating to the journeys of the individual vehicles are:

- Travel code;
- Description of the load;
- Length of the vehicle;
- Name and surname of the driver.

6.4.2. Interaction with the Blockchain

Most of the events just described in the USs involve an interaction with the blockchain. These interactions are outlined in Table 6. In detail, for each event, we specify the action involving the blockchain and the result of this action. For the sake of brevity, we do not report the actor involved in the US since it is already presented in Table 5. The actions will be performed by the smart contracts of the system.

6.5. Smart Contracts

Following the ABCDE method and focusing on the realization of the PoC, the choice was made to create the system with a single smart contract capable of storing all the information. This choice is functional to the rapid development of a demonstrator, but for a real system, the structure of the solution should certainly be more complex. Figure 8 shows, using the ABCDE conventions, a UML diagram of the contracts with the smart contract and the data structures used by it.
Table 6. Interaction events with the blockchain.

<table>
<thead>
<tr>
<th>User Story</th>
<th>Actions</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port entrance</td>
<td>Registration of plates and transport data on BC.</td>
<td>The SC contains the plates, ticket data, and the timestamp with a flag that locates the event (entrance to the port gate) and an id of the port of departure. Anyone with credentials can read the data.</td>
</tr>
<tr>
<td>Terminal arrival</td>
<td>Check the existence of license plates in BC.</td>
<td>Record the arrival at the terminal by writing on the BC and notarization the photos. The associated event is launched. Anyone with credentials can read the data.</td>
</tr>
<tr>
<td>Parking in the terminal area and semi-trailer uncoupling</td>
<td>Take the photos and upload the references on BC (hash of the file and link to the DB). Check tickets and flag registration on BC.</td>
<td>The hashes and links to the DB of the photos are loaded on BC. The associated event is launched. Anyone with credentials can read the data.</td>
</tr>
<tr>
<td>Boarding and lashing on the ship</td>
<td>Record the cargo on the ferry, noting which ferry it was loaded on.</td>
<td>The flag is set, the ferry id is entered, and the associated event is launched: the vehicle is on the ferry with the specified id or name.</td>
</tr>
<tr>
<td>Ship departure</td>
<td>It signals a ferry departure event (which concerns all the loaded vehicles) from a given port.</td>
<td>It is necessary to mark the departure flag for a specific ferry and a given port.</td>
</tr>
<tr>
<td>Ship arrival</td>
<td>Report a ferry arrival event (concerning all loaded vehicles).</td>
<td>It is necessary to mark the arrival flag for a specific ferry at a given port; you need the ferry id and the port id.</td>
</tr>
<tr>
<td>Disembarkation and arrival at the terminal</td>
<td>Record the unloading of the vehicle in the terminal, noting which ferry it disembarked from.</td>
<td>The landing flag is set, the ID of the ferry and port of arrival is entered, and the associated event is launched: the vehicle is in the port terminal with the specified id or name.</td>
</tr>
<tr>
<td>Parking in the terminal area</td>
<td>Take the post-landing photos and upload the references on BC (hash of the file and link to the DB). Check various documents (e.g. vehicle and cargo insurance) and flag registration on BC.</td>
<td>The hashes and links to the DB of the outgoing photos are loaded on BC. The associated event is launched. The arrival and documents check flag is set. Anyone with credentials can read the data.</td>
</tr>
<tr>
<td>Port exit</td>
<td>Driving license plate and trailer license plate check on BC.</td>
<td>The SC now contains the plates and the timestamp with a flag that locates the event (exit at the port gate). Anyone with credentials can read the data.</td>
</tr>
</tbody>
</table>

6.6. App Interacting with the Blockchain

The component of interaction with the blockchain includes the app software, i.e., the application that runs on a mobile terminal or PC and allows interaction with the blockchain, sending transactions, and carrying out queries. This software must necessarily manage a wallet as well, thus giving the possibility to generate and protect private keys, calculate public keys and addresses from these, and send transactions “signed” by the corresponding private key to the blockchain from a managed address.
6.6. AppInteract ing with the Blockchain

The component of interaction with the blockchain includes the app software, i.e., the application that runs on a mobile terminal or PC and allows interaction with the blockchain, sending transactions, and carrying out queries. This software must necessarily manage a wallet as well, thus giving the possibility to generate and protect private keys, calculate public keys and addresses from these, and send transactions signed by the corresponding private key to the blockchain from a managed address.

7. Discussion and Conclusions

This study provided a concrete Proof of Concept for the use of blockchain technology in managing roll-on roll-off traffic between ports. Although some previous studies predicted this technology as very promising, to the best of the authors’ knowledge, this is the first study that proposes a comprehensive analysis and concrete model to show how blockchain technology can be applied to roll-on roll-off transport, and interport communities in real environments.

Blockchain appears to have considerable potential to facilitate the development of interport communities as it can automate many activities, increase trust between parties, ensure transparency of operations, ensure the security and confidentiality of data transfer through a facilitated data-sharing platform, and guarantee the identities of the parties involved, especially for financial purposes.

There are numerous activities related to the maritime logistics chain that can benefit from the blockchain. The activities that can be most affected seem to be those related to the notarization of contractual documents, management of access authorizations, and passages of vehicles at the gates. The latter includes photographs and documents concerning the state of vehicles and cargo for insurance purposes. Of particular interest within an interport community is the possibility offered by the blockchain to securely share and
transmit information and notifications of logistical events between the various actors while preserving privacy and ownership of data.

In this paper, a new methodology specifically elaborated for the application of principles of software engineering and agile practices was applied to analyze, design, and build a complete Dapp system for implementing and supporting the development of an interport community with applications in the maritime industry, and to explore the application prospects and practical implications of blockchain technology for the establishment of such an interport community. The use of the ABCDE methodology and of blockchain Oriented Software Engineering allowed us to completely describe and represent the overall system’s architecture and the interactions among the components.

The perspective of this study is broad and not limited to the development of Smart Contracts, but also includes the analysis of the best-suited blockchain as well as the analysis of the actors eventually involved in the community, the description of user stories, and state diagrams representing the interactions among actors and the system and describing in detail how to perform and manage specific operations using the blockchain technology. All system requirements are illustrated, and all the possible events occurring in a real environment have been analyzed; for each of them, the study reports how the blockchain and the Smart Contracts can be used for full and concrete implementation. As a result, this paper represents a detailed document describing how to proceed with choosing the correct blockchain framework and implementing every single aspect of a concrete and applied system for managing an interport community through this new technology.

The paper also examined Strengths, Weaknesses, Opportunities, and Threats with a SWOT analysis that enlights how this technology can be very promising for the development of an interport community.

The potential advantages of blockchain in the port sector fall on a wide range of subjects. Both for-profit businesses and public authorities can take advantage of it. As for the former, subjects such as shipping companies, shippers, terminal operators, or transport companies can see their costs reduced, and their efficiency increased thanks to greater automation, the reduction in intermediaries and delays, but also the decrease in disputes and legal costs guaranteed by blockchain certification and smart contracts. Port authorities and other public bodies can also take advantage of the blockchain in terms of cost reduction, increased security, and greater guarantees of the respect of laws and regulations in the port area.

By way of example, we can mention a couple of specific benefits for the following stakeholders:

- Freight Forwarders: reduced paperwork through the digitalization of documents and automation of procedures and practices; access in real time to information; improvement of efficiency through error reduction;
- Terminal Operators: optimized use of terminal and yard thanks to accurate information about ship transit; improved lead time and frequency of inland and maritime transport services;
- Port Authorities: improved collection of transparent and unforgeable data; accurate and fast customs clearance process.

As for the cons, some opinions, not all justifiable, could negatively judge the introduction of the blockchain in an interport community, citing reasons related to the need to bear the costs of technological adoption and transition, the low propensity of the sector to increase transparency, the lack of trust against a new technology, possible privacy or governance issues. However, it is worth pointing out that the only reason that could actually limit the widespread adoption of blockchain technology in the maritime industry is not directly related to maritime transport but rather is rooted in the core structure of the technology: blockchain is a very energy-demanding technology, particularly from financial activities [49]. This aspect is crucial in the maritime sector, where, on the contrary, “green” and “low energy consumption” are the pillars that today guide the development of ports [50], in line with the United Nations Agenda 2030. It means that if blockchain
technology is to consolidate its presence in the maritime sector, it must pursue a sustainable “green” path to reduce its energy consumption. This will be the challenge that blockchain developers and experts will face in the near future.

**Author Contributions:** Conceptualization, P.S., G.F., R.T. and L.M.; methodology, P.S., G.F., R.T. and L.M.; software, R.T. and L.M.; formal analysis and investigation, P.S., G.F., R.T. and L.M.; writing—original draft preparation, P.S. and L.M.; writing—review and editing, P.S., G.F., R.T. and L.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by the EasyLog project funded under the Interreg IT-FR Maritime Program 2014–2020 (Easylog—Project number_196).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data is contained within the article.

**Conflicts of Interest:** The authors declare no conflict of interest.

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