A Blockchain Prototype on Container Shipping Operations

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Keywords: blockchain ; electronic seal ; game theory ; container terminal ; prototype simulation

1. Introduction

Maritime transport has become a critical operation in supply chains, given its development and globalisation, especially for international trade. Containers handle approximately 90% of world commerce, which makes shipping operations affect the coordination among the actors involved in this industry [1]. Moreover, its low-cost and high-efficient service makes maritime transport very attractive. However, shipping engages many complex transactions with confidential information, and the operation intensity on container terminals is increasing. Therefore, the container shipping industry is usually threatened under high-risk conditions because of the lack of a central system for organising the whole transport chain [2]. This leads to the need for stricter requirements to achieve efficiency, speed, and safety of data transmission on container terminals. Several leading worldwide ports have implemented different technologies to improve their core competency. Mobile devices (apps), real-time monitoring, sensors, and electronic seal technology are applied to enhance handling processes and security issues.

An electronic seal (hereafter called e-seal) is most widely used for indicating tamper activities during container transport. E-seals serve as transponders to track shipments, ensure their integrity, and provide information about status, location, container content, and interactions. Therefore, they are electronic alternatives to mechanical container seals where a physical lock with an electronic device is located on the container's back door to communicate with the tracking system [3]. In other words, e-seals show potential benefits in streamlining container logistics within supply chains and automating certain decision-making processes at specific stages of the logistics process [4]. Although e-seals greatly support the detection of unauthorised attempts from malicious entities during container transport, they cannot resist unauthorised access but only prove and record the existence of illegal intrusions that have occurred when e-seals are damaged or destroyed [5]. Therefore, sometimes it is hard to attribute an accurate time to when the tampering activity happened. For this reason, the traceability of the e-seal is a characteristic that should be strengthened for better data security.

Blockchain technology has been proposed as a solution to these concerns. It is a decentralised ledger system that can record and track transactions in a secure and transparent manner. Moreover, it is possible to create a tamper-proof record of the container's movements and status throughout the shipping process using blockchain to record the data from e-seals. Despite the great benefits of blockchain implementation, this technology has been mostly explored in theory for shipping operations. There is barely any structural simulation in real scenarios, and it is rarely addressed in the literature [6].

Hasan et al. [7] proposed a blockchain-based solution integrated with smart contracts to manage shipped containers of pharmaceutical goods. The smart containers were equipped with Internet of Things (IoT) sensors for tracking shipping conditions. The blockchain handles transactions among the stakeholders. Ref. [8] implemented IoT sensors with blockchain technology and smart contracts for transporting medical products. Komathy [9] proposed a framework to integrate blockchain in cargo shipping operations aiming to connect users with smart transactions and reduce delays. In addition, the transactions were validated to guarantee security and authenticity. Bauk [10] developed a conceptual framework of a blockchain for shipping management jointly with crypto-currency payments, smart contracts, and cargo tracing using Radio Frequency Identification (RFID) technology.

2. A Blockchain Prototype for Improving Electronic Seals on Container Shipping Operations

Blockchain is becoming a technology that supports different methods for solving problems in various fields. For instance, blockchain reduces the high cost of transactions by preventing wilful fraud or theft in real-time monitoring [8][11]. Moreover, it protects digital copyright from plagiarism by offering decentralised validation authority and a piracy tracing system [12]. However, there are many other applications of blockchain, as summarised in **Table 1** based on the literature review by Sunny et al. [13].

Table 1. Applications of blockchain technology.

Industry	Area
Transportation	**Traffic conditions [14][15], payment systems [16], energy [17], data distribution [18][19][20][21]**
IoT	**Smart cities [22][23][24], industrial operations [25], supply chain operations [26][27], agriculture [28][29][30][31][32], smart contracts [33][34]**
Finance	**Banking [35], tourism [36], product traceability [32], trading [37][38], data administration [39]**
Security	**Healthcare [40], finance [41][42], Apps [43][44], automobile industry [45][46]**
Government	**Land property [47][48], certification and registration [49][50], voting [51][52][53]**

For shipping operations, blockchain technology substantially improves all logistical processes from storage to payment, increases security and transparency, and speeds up the flow of goods [54][55]. In addition, blockchain involves different mechanisms to decrease the impact of cyber-attacks [1]. Jović et al. [1] provided the leading blockchain applications in the shipping industry. Maersk and IBM developed “Tradelens”, a solution focused on improving provenance and transparency [56]. The platform aimed to reduce the cost and complexity of trading and the need for documentation [57]. In addition, it allowed the safe sending and signing of contracts, while the blockchain-based smart contract led to faster approvals and information processing. Another example is the platform for containerisation in shipping called “Global Shared Container Platform”, developed by the company Blockshipping [58]. This technology is focused on providing transparency in operations that involve a large number of stakeholders. Further, CargoX introduced a Blockchain Documentation Transaction System to store encrypted data and exchange documents using smart contracts [59].

2.1. Comparative Analysis between RFID and Blockchain Technology

RFID technology has been widely adopted for improving the security of e-seals in container terminals [60][61]. However, it has limitations on security, as it is vulnerable to hacking and cloning. This highlights the need for a more secure and efficient solution, such as blockchain technology. While some authors may argue that using RFID on e-seals is comparable to using blockchain technology, it is suitable to note that there are significant differences between them. **Table 2** outlines the differences between RFID and blockchain on e-seals.

Table 2. RFID vs. blockchain for e-seals.

Feature	RFID	Blockchain	References
Encryption	**To secure data transmissions**	**To secure data transmissions**	[60][61]
Authentication	**Relies on access control based on a tag**	**Uses digital signatures for authentication**	[60][62]
Physical security	**Limited**	**High level of robustness**	[63]
Vulnerability management	**Very vulnerable to hackers**	**Relatively secure against hacks**	[62][64]
Access controls	**Limited to those with RFID readers**	**Flexible access controls**	[61][63]
Audit trails	**Limited audit trail capabilities**	**Robust audit trail capabilities**	[62][64]
Physical environment	**Susceptible to physical attacks and interference**	**Can be accessed from anywhere with an internet connection**	[65]

RFID and blockchain have their strengths and weaknesses regarding the security of electronic seals of containers. Both RFID and blockchain technology use encryption to secure data transmissions. However, blockchain technology also uses digital signatures for authentication for an extra layer of security. Physical security is an important factor for electronic seals of containers. Blockchain technology offers a higher level of security compared to RFID. While RFID tags can be physically compromised, blockchain provides a distributed and decentralised system that is more difficult to tamper with.

Moreover, **Table 2** shows that the two technologies must be updated with the latest security patches and firmware updates. Blockchain is relatively secure against hacks, whereas RFID is vulnerable to hacking and other security issues. On the other hand, RFID access is limited to those with RFID readers, while blockchain technology allows for flexible access controls, which can be beneficial in certain situations. Audit trails are essential for keeping track of all activities related to electronic seals, and blockchain technology provides robust audit trail capabilities, while RFID offers limited capabilities in this regard. The physical environment is also a factor, and while RFID can be susceptible to physical attacks and interference, blockchain can be accessed from anywhere with an internet connection, which can be a significant advantage in certain situations.

2.2. Comparative Analysis of Blockchain Developed Methods for E-Seal Prototypes

In recent years, the implementation of blockchain technology has gained significant attention in different industries, including logistics [18][19][20][21]. With its potential to enhance security, transparency, and efficiency in data management, blockchain technology has been explored in numerous logistics applications. Implementing an e-seal in containers requires a secure and reliable system that protects data transmission, ensures identity verification, and provides a robust solution for complex logistics operations. Therefore, the method used here for developing a blockchain prototype for an e-seal emphasises security, identity verification, and robustness, which are essential in the container logistics industry. **Table 3** shows that, compared to other methods, blockchain stands out due to its emphasis on security, identity verification, and robustness.

Table 3. Advantages and disadvantages of blockchain development methods for e-seal prototypes.

Method	Description	Advantages	Disadvantages
Smart Contract Development	**A programmable blockchain protocol that executes automated actions based on predefined conditions**	**Flexibility, transparency, automation**	**Complexity in developing and testing the smart contract code**
Permissioned Blockchain	**A blockchain network where access is restricted to authorised parties**	**Improved privacy, scalability, and performance**	**Lack of decentralisation, less secure than public blockchain**
Tokenization	**Physical or virtual assets as digital tokens on a blockchain**	**Improved liquidity, faster transactions, fractional ownership**	**Regulatory uncertainty, potential for fraud and hacking**
Proof of Authority (PoA) Consensus Algorithm	**A consensus algorithm where validators are selected based on their identity and reputation**	**Faster consensus, lower energy consumption**	**Centralisation and lack of resilience compared to Proof of Work (PoW)**
Interoperability	**A feature that allows different blockchains to communicate and share data with each other**	**Improved scalability, more efficient data sharing**	**Complexity in implementation, potential for security risks**
This paper	**Consortium-based blockchain with elliptic-curve (ECC) based e-seal scheme and PoW consensus algorithm**	**High security level, identity verification, robust e-seal scheme**	**Inefficiency and high energy consumption of PoW**

While Smart Contract Development offers flexibility and automation, it is a complex way of developing/testing smart contract coding. Permissioned Blockchain provides improved privacy, scalability, and performance. However, it lacks decentralisation and is less secure than public blockchains. Tokenization offers improved liquidity and faster transactions but may face regulatory uncertainty and potential security risks. PoA consensus algorithm provides a faster consensus and lower energy consumption, but it is centralised and less resilient. Finally, interoperability offers improved scalability and data sharing but can be complex to implement and may also pose security risks.

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