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Is Blockchain Technology Delivering an Efficient Framework for Electronic Bills of Lading?

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ABSTRACT

This article explores the potential of blockchain technology to provide an efficient and legally compliant framework for electronic bills of lading (eBLs). It evaluates the technical, operational, and legal features of blockchain systems, focusing on their capacity to overcome the limitations of earlier digital documentation models. Through decentralised consensus, cryptographic security, and immutable ledgers, blockchain ensures trust, transparency, and document integrity without reliance on centralised intermediaries. The analysis also examines the role of smart contracts in automating performance obligations and assesses the compatibility of blockchain with the UNCITRAL Model Law on Electronic Transferable Records (MLETR), particularly in relation to uniqueness, exclusive control, identification, time/place indication, and integrity. The article concludes that blockchain-based eBLs not only satisfy the MLETR's functional requirements but also enhance the commercial reliability and legal certainty of maritime trade documentation.

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Introduction

Blockchain technology presents a viable solution to the technical and operational deficiencies that have impeded earlier models of electronic bills of lading. As highlighted by The Economist, blockchain functions as a "trust machine," establishing reliability not through a centralised authority but via a consensus mechanism among distributed and independent network participants. This decentralised architecture not only facilitates trust but also ensures transactional transparency by maintaining an open ledger accessible to all authorised stakeholders [1,2].

Moreover, blockchain's structural attributes render it particularly well-suited for the digitalisation of transferable documents, such as bills of lading. It guarantees document singularity through the chronological recording and validation of transaction histories within discrete, immutable data blocks. This feature mitigates risks of duplication and fraud, which are significant concerns in the use of electronic documents in international trade [3].

Beyond merely replicating the functionalities of paper-based bills of lading, blockchain technology also supports the integration of smart contracts. These programmable agreements enable the automatic execution of contractual obligations embedded within the bill of lading, contingent upon the fulfilment of predefined conditions. Such automation enhances efficiency, reduces transactional friction, and minimises human error in maritime commercial operations.

A Conceptual Overview of Blockchain Technology

Blockchain technology constitutes a novel framework for decentralised data storage and management [4]. Initially developed in 2008 by the pseudonymous figure known as Satoshi Nakamoto, blockchain was primarily introduced to facilitate the operation of Bitcoin, a decentralised digital currency [5,6]. Despite its close association with cryptocurrencies, blockchain has since evolved into a foundational technology with far-reaching applications across various domains, including trade documentation and maritime logistics [7].

At its core, blockchain operates as a digital ledger that records transactional data [8]. It is both decentralised, free from control by a single central authority, and distributed, meaning all participating nodes in the network possess access to the entire transaction history [9]. Security and authenticity are maintained through cryptographic protocols rather than reliance on traditional intermediaries such as banks. Validation of transactions is carried out by network participants (nodes), who collectively authenticate updates through consensus mechanisms.

The blockchain ledger is composed of sequential ‘blocks’, each containing a batch of verified transactions [10]. New blocks are added through a computationally intensive process called ‘mining’ [11]. Upon successful validation, a block is appended to the existing chain, with the inclusion of the hash value of the preceding block ensuring the integrity and chronological continuity of the ledger [12,13]. This validation process, termed Proof of Work (PoW), is a characteristic feature of permissionless blockchains such as Bitcoin [14].

An alternative to PoW is the Proof of Stake (PoS) mechanism, which addresses the high energy consumption associated with PoW [15]. In PoS systems, validators are selected based on the proportion of the network’s total value they hold, referred to as their "stake". While PoS increases energy efficiency, it tends to

create less decentralisation compared to PoW-based networks, as participation in validation is limited to higher-stake holders [16].

Blockchains may further be classified by access rights and governance models. In terms of access, blockchain systems are either permissionless or permissioned. The former permits open participation, allowing any user to view, validate, and add transactions upon downloading the requisite software [17]. In contrast, permissioned blockchains restrict these functions to authorised users, with varying degrees of access and control tailored to the needs of the platform [18].

From a governance perspective, blockchains can also be public or private. Public blockchains are governed collectively by the network and require no central administrative authority [19]. Decisions regarding transaction validation and data storage are made through consensus among anonymous nodes [20]. Conversely, private blockchains are managed by a centralised, trusted authority that designates which users may validate and store data, thereby limiting participant anonymity [21].

Permissionless public blockchains, such as Bitcoin, are inherently more secure due to their openness and redundancy. The existence of multiple identical copies across countless nodes renders unauthorised alterations virtually impossible. Nevertheless, private permissioned blockchains remain appealing in certain contexts. Their hierarchical structure can simplify administrative processes and accommodate commercial sensitivities regarding data privacy and access restrictions. For instance, businesses may adopt such models to retain control while benefiting from blockchain's advantages in transparency and efficiency [22].

Although these private systems may still rely on conventional notions of trust, rather than algorithmic consensus, they offer improvements over existing closed platforms used for electronic bills of lading. Importantly, they reduce dependency on central registries, which have traditionally been a source of commercial mistrust. Regardless of the specific blockchain architecture employed, the technology is capable of securely managing title and associated documentation with a level of decentralisation that surpasses that of many current electronic systems [23].

Smart Contracts

An important technological innovation that must be considered alongside blockchain is the concept of the smart contract, first introduced by Nick Szabo in 1994[24]. Despite its name, a smart contract is arguably neither "smart" in the cognitive sense nor a legally binding "contract" in the traditional sense [25,26]. Rather, it refers to self-executing and self-enforcing digital protocols that perform certain actions automatically when predefined conditions are met. Their designation as "smart" stems from their capacity to eliminate the need for third-party intervention by automating transactional processes [27].

Smart contracts predate blockchain technology and are therefore not inherently a feature of blockchain systems. They are, in essence, digital agreements expressed in computer code that monitor, execute, and enforce themselves based on a conditional logic structure [28]. These programmes typically follow an "if-then" format: for instance, "if the goods are unloaded at Port X, then the payment shall be released [29]." The logic embedded within such code reflects the agreed obligations of the parties and automatically administers outcomes such as entitlements or sanctions, based on compliance.

The integration of blockchain technology with smart contracts has been widely recognised as a means of enhancing the efficiency, reliability, and decentralisation of trade documentation systems, including electronic bills of lading [30]. Blockchain serves to strengthen the operational integrity of smart contracts by ensuring that they are immutable (tamper-proof), efficient (by reducing reliance on intermediaries), and pseudonymous (protecting user identities while maintaining transparency) [31].

Both permissionless and permissioned blockchain-based platforms for electronic bills of lading are increasingly incorporating smart contracts into their operational frameworks [32]. Their deployment promises not only improved automation of contractual performance but also a move away from the reliance on centralised authorities that characterises many current electronic document systems. As such, the synergy between blockchain and smart contracts represents a significant development in the modernisation and decentralisation of trade logistics and legal documentation.

Applicability of Blockchain Technology to Electronic Bills of Lading under the Current Legal Framework

Guarantee of Uniqueness

A core requirement under the UNCITRAL Model Law on Electronic Transferable Records (MLETR) for an electronic record to function as the legal equivalent of a paper bill of lading is its uniqueness. This condition is essential to ensure that only the legitimate holder may exercise the rights embodied in the document and to prevent issues such as double-spending or multiple transfers of the same entitlement [33]. Blockchain technology offers a technical mechanism capable of satisfying this legal requirement through its inherent design.

The structure of blockchain, where transactions are chronologically confirmed and appended block by block following the resolution of a complex computational challenge, ensures that each entry is immutable and time-stamped. Through cryptographic hashing and decentralised consensus, blockchain systems can reliably identify the first legitimate transfer of a token and invalidate subsequent unauthorised attempts. This capability allows blockchain-based bills of lading to maintain the requisite singularity and integrity of title transfers.

In addition to chronological priority, blockchain also addresses the principle of exclusive control, another criterion under the MLETR which serves as a functional equivalent to the physical possession of a paper bill. Historically, legal and commercial actors presumed that such control could only be assured through centralised registry systems. While the theoretical production of a unique and transferable electronic record was conceivable, the practical absence of enabling technology at the time meant that reliance on central registries was unavoidable.

However, the advent of blockchain now offers a credible decentralised alternative: by utilising distributed ledger architecture and cryptographic keys, blockchain enables the establishment of a unique digital record that is both exclusively held and transferable [34]. The holder of the private key associated with the digital address at which the electronic bill of lading is recorded is deemed to have exclusive control over the document [35]. In this sense, blockchain-based systems fulfil the MLETR's requirement of exclusive control by aligning technological capability with the legal concept of possession.

Consequently, blockchain technology not only facilitates the uniqueness of title records in the context of electronic bills of

lading but also replaces the traditional reliance on centralised oversight with algorithmic assurance, thereby reinforcing the legal validity and commercial reliability of such digital instruments within the existing legal regime.

Identification of the Person in Control

Two principal models exist for determining the identity of the person in control of an Electronic Transferable Record (ETR): the registry model and the token model. Under the registry model, control is attributed through reference to a centralised third-party registry, which maintains authoritative records of entitlement [36]. By contrast, the token model establishes control within the ETR itself, whereby the record inherently contains the mechanisms for identifying and transferring control without reliance on external validation [37].

Blockchain-based bills of lading align with the token model [38]. In such systems, the distributed ledger comprises a series of cryptographic addresses at which tokens, representing transferable records, are stored. Each address is derived from a public key, which in turn is generated from a corresponding private key. The private key confers control, such that the individual in possession of the private key to a particular address is deemed to be in control of the associated token. Consequently, the address functions as a cryptographic proxy for the holder's identity [39].

Importantly, while the private key remains confidential, the associated public key may be made visible on the blockchain. Disclosure of the public key does not require revelation of the holder's real-world identity. Thus, control of the token is established through possession of the private key, while the actual identity of the holder may remain pseudonymous. However, this does not preclude the possibility of the holder verifying their identity through supplementary means if required [40].

The approach taken by the UNCITRAL Secretariat confirms that identification of a person in control need not rely on their legal name [41]. The law may accommodate alternative methods of demonstrating identity, including cryptographic identifiers. As such, blockchain technology is fully compatible with the legal framework governing electronic transferable records. It provides a secure and reliable method for establishing and verifying control over an ETR, while preserving the flexibility required for legal recognition of non-traditional forms of identification.

Indication of Time and Place in Electronic Transferable Records Article 13 of the UNCITRAL Model Law on Electronic Transferable Records (MLETR) provides that, where the applicable law requires or permits the indication of time or place in relation to a transferable document, such a requirement is deemed fulfilled if a reliable method is used to establish that time or place. Blockchain technology, through its distributed ledger architecture, inherently satisfies this condition by employing a time-stamping mechanism that ensures the chronological ordering of all recorded transactions.

Specifically, each transaction recorded on a blockchain is accompanied by a timestamp generated by the system's time-stamping server, which serves as a cryptographic means of documenting the precise moment at which the transaction occurred. This feature ensures that every transfer or endorsement of a blockchain-based bill of lading is verifiably linked to a specific point in time.

Furthermore, in resolving competing claims to the same electronic bill of lading or determining the proper sequence of transactions, participants in a blockchain system rely on the ledger's immutable history. They refer to the established chronological order of blocks, each containing time-stamped transaction data, to identify which version of the bill of lading holds legal primacy [42]. In this way, blockchain technology provides a reliable and legally compliant mechanism for indicating both time and place, aligning with the evidentiary requirements contemplated by Article 13 of the MLETR.

Integrity of Blockchain-Based Bills of Lading

To be recognised as a valid substitute for paper-based bills of lading, a blockchain-enabled electronic bill of lading must satisfy the legal requirement of integrity, as articulated under Article 10 of the UNCITRAL Model Law on Electronic Transferable Records (MLETR). This provision stipulates that an electronic transferable record maintains its integrity where any information relating to authorised modifications remains complete and unaltered from the time of the record's creation until it ceases to have legal effect [43].

In this regard, blockchain technology demonstrates considerable superiority over traditional paper documentation. The integrity of blockchain-based systems is maintained through a synthesis of advanced cryptographic methods and decentralised consensus protocols, which collectively serve to preserve both the authenticity and immutability of transactional records.

The integrity assurance process can be summarised as follows: it begins with the generation of a cryptographic key pair, comprising a private and a corresponding public key, by the sender. While the public key is openly shared, the private key is retained confidentially by the sender. To ensure the data's integrity, the sender processes the content through a hashing algorithm, which produces a fixed-length string that uniquely represents the original data. This hash value is then encrypted with the sender's private key, thereby generating a digital signature [44].

This digital signature performs two critical functions: it authenticates the sender's identity and confirms that the message has not been altered during transmission. Upon receipt, the recipient may validate the document's integrity by decrypting the signature using the sender's public key and comparing the resulting hash with a freshly computed hash of the received content. A match indicates that the data has remained intact and unmodified.

Beyond cryptographic safeguards, blockchain's structural reliance on decentralised verification further enhances integrity. Each new block of data can only be added to the ledger upon validation by a majority of independent nodes within the network, a process that ensures only legitimate and tamper-free transactions are recorded. This consensus mechanism, combined with the immutable and time-sequenced nature of blockchain, significantly reduces the potential for fraudulent alterations or post-creation modifications.

In sum, the integration of encryption-based verification and distributed consensus mechanisms enables blockchain-based bills of lading not only to comply with the MLETR's integrity standard but to exceed the reliability and evidentiary assurance provided by conventional paper-based instruments.

Conclusion

Blockchain technology offers a transformative framework for the digitalisation of bills of lading, addressing many of the technical, operational, and legal deficiencies that have historically hindered the implementation of electronic equivalents. By decentralising trust through consensus mechanisms, ensuring transactional

transparency via immutable ledgers, and enabling document singularity, blockchain eliminates much of the reliance on centralised intermediaries long a source of friction in maritime commerce.

Its compatibility with smart contracts further enhances the efficiency and functionality of electronic bills of lading by automating the performance of contractual obligations, thus reducing human error and procedural delays. As demonstrated, both permissioned and permissionless blockchain architectures can accommodate commercial and regulatory expectations while offering varying degrees of openness, security, and control.

From a legal standpoint, blockchain technology aligns closely with the key requirements of the UNCITRAL Model Law on Electronic Transferable Records (MLETR). It satisfies the functional criteria of uniqueness, exclusive control, identifiability, time and place indication, and integrity, which are essential for establishing electronic transferable records as legally valid substitutes for paper-based instruments. Notably, the ability of blockchain systems to identify the person in control without necessitating real-world identification, and to preserve integrity through cryptographic signatures and consensus validation, reflects a technological maturity well-suited to the demands of international trade law.

In light of these observations, it may be concluded that blockchain technology not only delivers an efficient and secure infrastructure for electronic bills of lading but also paves the way for a broader reconfiguration of trade documentation in line with the principles of decentralisation, automation, and legal certainty. As adoption grows and legal frameworks such as the MLETR continue to be implemented across jurisdictions, blockchain is poised to become a foundational tool in the future of maritime trade and digital commerce.

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