Evaluating the integration of Blockchain Technologies in Supply Chain Management: a case study of sustainable fishing

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***Abstract*—As a consequence of the Global pandemic, Supply Change Management (SCM) is becoming more complex due to market uncertainty across value chains; from sourcing materials to logistics and production. With the development of contemporary technology, blockchain may allay this worry by providing the SCM industry with automated software solutions. Blockchain is an emerging technology that supports a distributed and transparent approach to transactions between various entities. Due to increased digital usage across many sectors, the technology is being adopted more commonly in real-world business applications that aim to achieve transparency and security along a distributed chain of processes. Examining how these applications are deployed, based on the respective domain creates opportunities for future research and in advancing current thought processes of supply chain practitioners. This research aims to assess the fishing industry and provide a solution to trace the complete seafood lifecycle by capturing, recording, and tracking all relevant activities and data (e.g., video, photo, documents) from "bait to plate" and provide an open and immutable history record for each transaction in the supply chain of this lifecycle. The research offers valuable insight for supply chain practitioners into how blockchain technology has the potential to disrupt existing supply chain deployments and highlights some challenges of its successful adoption. Emerging blockchain applications aim to help businesses, including supply-chain transparency for a wide range of products**

***Keywords*— Blockchain Technology, Seafood Industry, Sustainability, Supply Chain Management**

I. Introduction

In 2008, more than a decade ago, Satoshi Nakamoto, the anonymous creator of Bitcoin, revealed how blockchain technology, a decentralized, distributed peer-to-peer, immutable linked ledger, could be used to address the financial challenges of maintaining transaction orders and double-spending [1], [2]. 'Blockchain' can be explained as a distributed database, organized as a list of ordered blocks with immutable committed blocks. Each block can be considered as a data packet that is linked to the one before it and comprises all previous data as well as new data. The whole chain is a database that is shared among numerous people who share control of the blocks (i.e. it is not controlled centrally) [3].

The blocks in the blockchain can be made up of any kind of data such as personally identifiable information (PII), transaction details (such as payments), operations in a supply chain management (SCM), barcodes, etc. This means that the scope and potential of blockchain are vast and vary depending on the use case. In developing a blockchain, the ledger's nodes (i.e. blockchain miners) are in charge of chronologically connecting the blocks, ensuring each block includes the hash of the preceding block [3] allowing the system to keep reliable and auditable records for all transactions.

One of the practical uses of blockchain is supply-chain management, and the recent Coronavirus (COVID-19) pandemic emphasized the significance of how developing technologies can provide genuine and reliable commercial advantages. Growing customer expectations, diverse marketing channels, international obstacles, and a number of other issues have all made supply chains increasingly difficult to manage. A supply chain might involve several partners, spanning a large number of phases, operate in different countries, entail hundreds of invoices and payments, and last for a considerable amount of time due to shipping challenges [4].

Within the supply chain sector, the adoption of blockchain technology is still in its infancy. Two of the key elements influencing their acceptance inside SCM systems are traceability and trust. Breaking down these two essential elements into three additional sub-factors; increased supply chain visibility, digital supply chain transformation, and improved supply chain security and transparency will help to better understand how blockchain technology can progress the supply chain management industry [4]

II. Literature Review

Since its inception, the landscape of blockchain has rapidly evolved as technology expands beyond Bitcoin and other similar cryptocurrencies to other use cases, where Smart Contracts (SC) play a significant role [5]. Blockchain started out with its first iteration, Blockchain 1.0, which included applications that enabled digital cryptocurrency transactions. Over time, the technology further developed into Blockchain 2.0, which includes SCs and applications going beyond cryptocurrency transactions. The technology, now its third iteration, Blockchain 3.0 includes applications in fields beyond the first two iterations, such as Industry 4.0 and SCM, government digitization, healthcare, science, and IoT [6].

In 1994, Szabo described SCs as "a computerized transaction protocol that implements the provisions of a contract" [7]. Szabo explored converting contractual clauses into embeddable code using SCs [8], which reduces the need for external involvement and risks. Specifically, an SC is an agreement between parties whose terms are automatically enforced even if they do not trust one another [9]. In a blockchain, SCs are scripts that execute in a decentralized fashion, based on set terms and are kept in the blockchain without relying on a trusted authority [9], [10]. Therefore, blockchains designed with SCs enable complicated processes and interactions, establishing new paradigms and the potential for virtually endless blockchain use cases.

In recent years, blockchains have significantly disrupted traditional business processes since activities and transactions that once required centralized systems or reliable third parties to authenticate, may now function in a decentralized fashion with the same (or even higher) level of certainty. Fundamental characteristics that blockchain offers include immutability, traceability, transparency, resilience, and security [9], [11].

Consequently, Blockchain technology is growing in importance [6]. According to a 2017 report by IBM, almost a thousand (33%) of C-suite executives said they were exploring blockchains or were currently actively utilizing them [12]. Researchers and developers are already familiar with the potential of the new technology and are investigating its many uses across a broad range of industries [9].

III. Application Areas Of Blockchain In Supply Chain Management

There is a wide spectrum of possible use cases for blockchain technologies in SCM. As illustrated in Fig. 1, in 2019, Helo and Hao [13] summarized these use cases in three categories namely: (i) assets, (ii) identity and (iii) transactions.

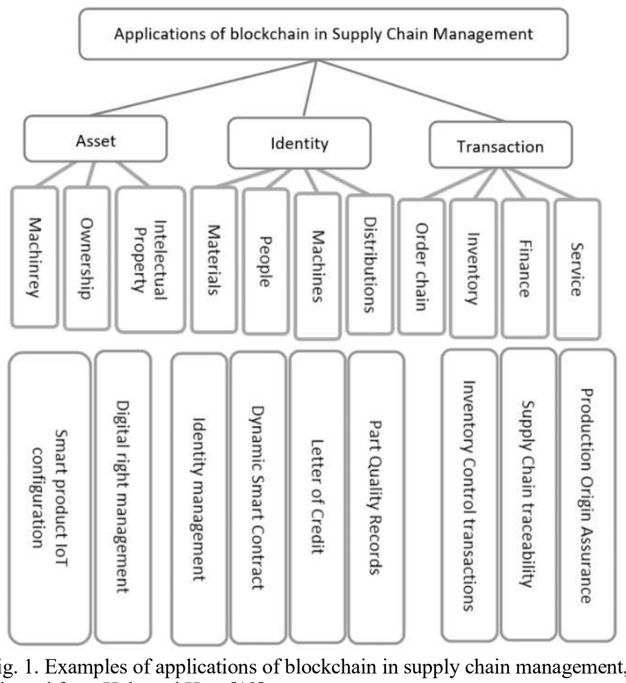

Fig. 1. Examples of applications of blockchain in supply chain management, adopted from Helo and Hao. [13]

A. Assets

It is essential to maintain accurate and trustworthy records to identify ownership and assure the accuracy and completeness of property-related important information for both tangible assets (i.e., physical property) and intangible assets (i.e., files) [14], [15]. By registering and trading the properties via blockchains through digital property management, it is feasible to establish the transfer of ownership and traceability of assets and their lifecycle via IoTs, [16]. Blockchain's cryptographic management of keys and signatures identifies who owns and can trade inside the shared ledger, ensuring the provenance, security and veracity of the ledger's stored assets [17].

B. Identity

Digital identity and private records, such as health records, licenses, ID cards, contracts, signatures, etc can be stored and authenticated with blockchain through securely encoded legal smart contracts. [3], [18]. Ultimately, code-based smart contracts are computer programs that can execute most of the agreements, contractual relationships, and governance [10], [17]. When a pre-configured condition in a smart contract among participating entities is met, the parties involved in the contractual agreement can automatically make transfers based on the contract in a transparent manner [3], [10].

C. Transactions

As relationships and interactions increasingly move online and are handled by automated processes rather than intermediary people, the traditional trust and confidence that most customers have relied on, are now either absent or can be forged through these online transactions [14]. The decentralized, immutable and distributed transaction ledger is one of the defining features of blockchain. This creates a permanent and verifiable record of transactions between parties [15]. All supply chain-related transactions, including orders, inventories, and goods, may be recorded and validated on the blockchain.

Supply chains are complicated because they consist of dispersed operations upstream, involving people, physical resources, and industrial processes, to downstream operations involving the entire selling process, including contracts, client sales, distribution, and disposal [16]. The objective of the supply chain is to develop a multi-stakeholder collaborative environment based on mutual trust, eliminate communication obstacles, and ensure that diverse businesses are interconnected to seek regular integration of the complete supply network [17], [18]. In the end, supply chain stakeholders may increase overall efficiency and provide higher value and advantages to their businesses through blockchain. Helo and Hao [13], simplified these advantages into five (5) key indicators as seen in Table 1.

TABLE I: TABLE ILLUSTRATING THE BENEFITS OF APPLYING BLOCKCHAIN IN SUPPLY CHAIN MANAGEMENT, ADOPTED FROM HELO AND HAO [13]

Supply chain indicators	**Blockchain key concepts**		
	Tamper-proof transaction records	*Information sharing & synchronization*	*Smart contract execution*
Improve overall quality	X	X	X
Reduce cost	X	X	X
Shorten delivery time		X	
Reduce risk	X		X

Increase trust	X		X	

IV. PROBLEM STATEMENT

The purpose of SCM systems is often to boost sales, lower manufacturing costs and complexity, eliminate fraud, and speed up production and delivery. Many businesses lack an integrated picture of the complete supply chain as supply networks are growing increasingly complicated in structure, challenging in terms of tasks, and diverse in terms of stakeholders. While big corporations have created their own identities and systems to sustain worldwide oversight of their operations and have the authority to engage and instruct their suppliers, many are struggling due to the pandemic. The situation is even worse for medium-sized and smaller corporations [19]. Many of them must rely on centralized regulatory authorities or middlemen. This has recently led to several internal and external constraints, including greater complexity, demand volatility, and a shifting retail environment, which are posing increasingly difficult problems for present SCM networks [4].

In terms of security, traceability, authentication, and the verification system, this lack of transparency creates a few concerns and challenges for the supply chain mechanism. In severe circumstances like COVID-19, this is more significant. As a result, certain chain suppliers temporarily stopped producing, and logistics companies were unable to move vital items like masks and ventilators as smoothly, especially across borders. It is noteworthy, that blockchain is well-suited to handle the difficulties of supply chains. Consequently, it is imperative to implement blockchain technology, with its immutability, transparency, and trustworthiness [20], to increase supply chain visibility and security.

Consumers are also requesting greater information about the origins of the products they purchase. Because of this, customers are prepared to pay more to businesses that have more transparent supply chains, which boosts not only sales but also customer happiness and confidence networks [4].

V. RESEARCH WORK

For the purpose of this research, sustainable supply chains, as explored by Hutchins and Sutherland [21], were assessed in an effort to design 'sustainability measures' for the seafood sector as well as guide similar future supply chain-related decisions. As described in the preceding section, blockchain is believed to provide enormous promise for strengthening supply chain management procedures and business models. A reference blockchain-based supply chain management system (BSCMS) was designed and implemented in the form of a proof of concept (POC) to provide a solution to trace the complete seafood lifecycle. The solution captures, cryptographically records and tracks all relevant activities and data (e.g. video, photo, documents) from "bait to plate" and provides an open and immutable history record for each transaction in the supply chain. The seafood industry is one of the world's largest and oldest market sectors. It is also the longest logistic network for food and is made up of complex global supply chains which creates numerous social and environmental challenges. Both illegal fishing and unreported fishing are malpractices destroying and deplete marine habitats, threatening sustainability. Enhancing provenance certainty, traceability, and transparency along these supply chains could be a way to resolve these problems. Blockchain technology is well-positioned to achieve these goals.

As illustrated in Fig. 2 below, depending on the underlying technologies, blockchain systems can be accessed in different ways and are categorized based on how they are accessed [22]. According to Yeoh [23] and Wu et. all [24], as illustrated in figure 2 below [22], there are three categories of blockchain systems:

- Permissioned based (private), in which verification nodes are recognized and identified by a central authority or database.
- Permissionless-based (public), in which anybody can participate in the verification process without permission.
- Hybrid, in which both permissioned and permissionless ledgers are utilized.

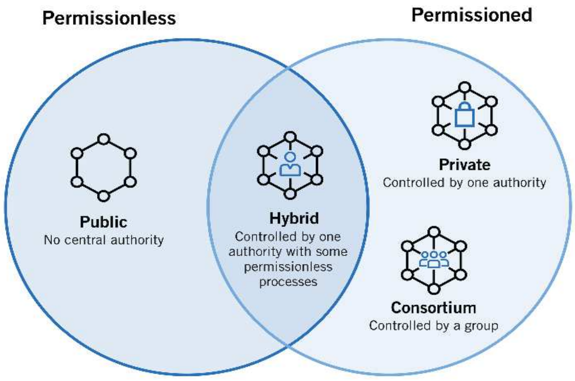

Fig. 2. Illustrating the blockchain architecture categories, adopted from Wegrzyn and Wang. [25]

In this research, a hybrid blockchain was selected to handle the process. Using either a fully public or entirely private ledger architecture for the flow of information makes it challenging to meet the practical needs of blockchain applications. For the proposed solution, it is vital to synchronize the two types of ledgers, a private ledger is utilized for sensitive data, whereas a public ledger is utilized for material that requires a high level of confidence. Without relying on a centralized governing body, each participant can control information access via the two forms of ledgers [24].

VI. DESIGNING THE BLOCKCHAIN WORKFLOW

The framework and the corresponding system architecture are composed of three layers, as seen in Fig. 3. This platform consists of several fundamental technologies and provides technical modules. This architecture is flexible and can be adapted based on realistic requirements for varying SCM sectors.

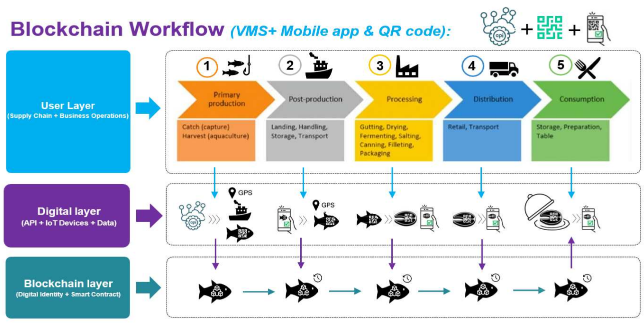

Fig. 3. Blockchain-based supply chain management system architecture.

- User Layer: This layer comprises the supply chain and business operations. This layer includes various users.

Each partner can monitor the quality of the supply chain and perform various business activities with the support of blockchain.

- The Digital Layer: This layer comprises both data collection and amalgamation to feed into the blockchain. Along the supply chain, different types of data (geo-location, weight, species, transactions, etc.) are either captured by IoT devices in real-time or imputed by users. All users, including logistics operators and consumers, keep a copy of different aspects of the data supply chain operations.

- The Blockchain Layer: This layer offers a secure data-sharing infrastructure in a distributed network. When the data is gathered and shared in the digital layer, it will be digitally signed and added to the blockchain, facilitating supply chain monitoring and traceability. Digital identity is used to secure the authenticity of the data while the Smart contracts perform real-time quality monitoring by using real-time data.

Conceptually, a blockchain is governed by decentralized consensus and coherence. The logistical history data are reliable, precise and consistent. They can be preserved without the participation of a reliable mediator. Customers and logistics providers have complete access to their respective data [25]. The conceptual environment of the BSCMS established for this study is depicted in Fig. 3. The system focuses on the fishing industry in the United Kingdom.

VII. Software Implementation

The functionalities of the system consist of transaction entry for supply chain operators which includes five (5) main stages:

1. Operators are authorized users. The user logs a transaction containing information on supply chain operations, seafood types, geolocation, timestamps, and health certificates. In addition, the transaction comprises the package's state, such as pickup, receipt, quality check, or final delivery.

2. A new block is offered and distributed to all peers in the supply chain network whenever a new logistical transaction is created.

3. Participants in the network get the block for validation. The system will place the new block into the chain after all participants have authorized it. This enables both clients and operators to have an efficient, verifiable, and permanent global perspective of the transaction history.

4. Once a block has been included in the chain, its data cannot be altered because the block is signed to the preceding block's cryptographic hash.

5. The transaction is complete after the authorized block has been added to the chain.

The architecture of BMLS is structured into two parts: (1) the back-end: which comprises the digital layer and the blockchain network working together to issue and verify digital certificates, and (2) the front-end: where users interface and interact with transactions.

The blockchain's backend design facilitates distributed transaction operations through codes SCs. Each block in the blockchain includes transaction information that links to the preceding block. In the verification process, multiple server computers perform the verification procedure, flag anomalies and ensure the data's immutability. Data can also be saved on distributed servers, although for the sake of this proof-of-concept, local storage was employed for speedy package number searches.

VIII. Results/Analysis

A. The Issuing Process

Using blockchain technology, the POC designed for this research aimed to improve sustainability for supply chain management in the fishing sector. The implementation accounted for the entirety of the supply chain, from 'bait to plate' (Catching the seafood straight through to consumption). The developers created a uniform API that uses blockchain technology to record verified transactions. The API employs several data types, data sources, and data formats to generate and issue digital passports. Fig. 4 depicts how data supplied via the API is added to a blockchain to issue.

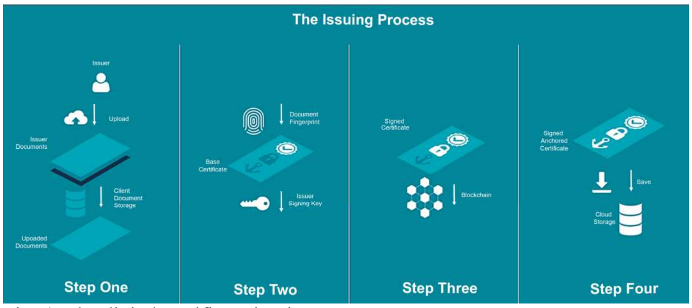

Fig. 4. The digital certificate issuing process.

Users have the opportunity to upload documents, which would automatically be digitally encoded and added to the blockchain. The final generated certificate is an immutable record that will encompass all pertinent information, documents, data, and assets as a sequence of unalterable occurrences in the seafood life cycle.

B. The Verification Process

Fig. 5 illustrates the verification process, where users or third parties are able to check the validity and file integrity of the generated certificated (digital passports) using the application. Users may also download the digital passport, submit it to an external protected portal, and verify its validity by comparing it to the original digital passport that is stored on the blockchain.

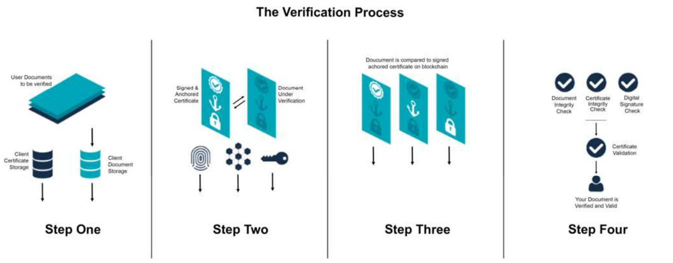

Fig. 5. The digital certificate verification process.

The result is a digital passport containing all pertinent information or assets to be anchored to the blockchain. The digital passport becomes an immutable record that serves as the record's gold standard. The digital passport has a unique, clickable and scannable QR code that redirects and validates against the original file stored on the blockchain. Every stage of the seafood's journey is made accessible to customers, through a digital passport (as seen in Fig. 6), therefore increasing their understanding and transparency.

Fig. 6. The digital passport segments.

IX. Discussion

In this study, the BSCMS is an exploratory reference implementation. We chose this method because blockchain is still considered to be in its infancy. Our objective was to provide a platform to increase the sustainability of supply chain-related operations while ensuring the confidentiality and transparency of all activity records. Numerous real-world business applications are adopting other use cases for transparency and security throughout a dispersed chain of activities. Two examples are mentioned below:

A. *Safety and Tracking*

Safety plays a crucial part in several businesses. Authentic food, for example, is a vital aspect of sustainability. Generally, counterfeit food poses a concern to public health. To resolve food safety challenges, transparency in food supply chain management is essential. Tracking and tracing are common supply chain operations for achieving informational transparency. Blockchain facilitates this transparency through an immutable database for transactions, users, locations, containers, etc. within the food sector. [26]. In 2016, Walmart teamed with IBM to build a blockchain-based system which significantly improved the transparency of both local and international supply chains. The use case merged blockchain with auto-ID technology to immediately trace the provenance of food in the event of a foodborne illness epidemic [26].

B. *Identification Systems*

Counterfeit pharmaceuticals pose a concern that blockchain technology can help to remediate[27], [28]. In the medical industry, it is well-known that counterfeit pharmaceuticals, such as anti-cancer treatments, can have fatal repercussions if patients do not receive therapy as recommended [27]. By enabling supply chain transparency from manufacturers to wholesalers to pharmacies to consumers, blockchain can improve patient safety. Through auto-ID technology, patients may verify that they have got the correct medication [27], [29] and trace it back to the point of origin.

As more parties in the supply chain use blockchain technology, it becomes more legitimate and valuable, eventually becoming an industry standard. However, early stakeholder buy-in will be challenging due to varying levels of digital preparedness [29], high implementation costs and a lack of supportive regulatory mechanisms around the technology [2]. It is crucial to establish standards and agreements around the technology to ensure interoperability across various blockchain-based systems [30]

X. Conclusion

Blockchain technology adoptions are still considered to be in the early stages within the supply chain industry. Traceability and trust are two of the major factors driving their adoption within SCM systems. Understanding how blockchain technologies advance the supply chain management sector lies in breaking down these two key factors into further three sub-factors (i) increased visibility along the supply chain, (ii) digital transformation of supply chains, and (iii) enhanced security and transparency within the supply chain.

There are several challenging aspects of the supply chain that make it extremely complex to manage. For example, numerous parties are engaged in the supply chain, a shared common database is required, and once recorded, transactions are rarely altered. Therefore, supply chains may be progressively optimized by utilizing a digital infrastructure environment such as blockchain, in which all involved parties can exchange, access and meticulously monitor product-related information in real time. Ultimately, the technology considerably decreases SCM's complexity [31] and increases sustainability.

Numerous logistics operators, particularly small and medium-sized businesses, claim to have limited awareness of blockchain and view its influence as a danger [32]. Although logistics and supply chain management blockchain research is still in its infancy, small-scale experiments such as the one in this research should be conducted by businesses to gain first-hand knowledge [4].

To increase the understanding of blockchain technologies, this project designed a prototype of a blockchain-based supply chain management system (BSCMS). This BSCMS acquired and communicated logistical data utilizing a blockchain approach. The capability of the system enables clients, logistic operators, and any other partners to follow the complete lifecycle of seafood, from capture to consumption. The proposed reference architecture illustrates how blockchain may be implemented utilizing components in operational and supply chain contexts. Our findings indicate that, in contrast to traditional IT designs, blockchain technology is a potential platform to improve supply chain management sustainability by introducing transparency, automation, and trust.

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