Blockchain Interoperability Issues in Supply Chain: Exploration of Mass Adoption Procedures

KAYIKCI, Yasanur <http://orcid.org/0000-0003-2406-3164> and SUBRAMANIAN, Nachiappan

Blockchain Interoperability issues in Supply Chain: Exploration of mass adoption procedures

Yaşanur Kayıkcı[1, *] and Nachiappan Subramanian[2]

[1] Turkish-German University, Department of Industrial Engineering, Istanbul, Turkey
yasanur@tau.edu.tr
[2] University of Sussex Business School, Science Policy Research Unit, Brighton, UK
N.Subramanian@sussex.ac.uk

Abstract: Today's supply chains are becoming more data-driven with the impact of big data, but there are many challenges that need to be overcome in big data for better service operations management in supply chains. Blockchain has the great potential to improve big data services and applications with its decentralisation and security nature. However, blockchain interoperability is critical to realising more value creation in blockchain networks and achieving promising results for global supply chains that intersect with multiple business ecosystems and blockchain platforms. In addition, it is unclear how to address interoperability issues for mass adoption. In this chapter, a three-step approach is applied to analyse blockchain interoperability in supply chains for mass adoption. First, a literature review is conducted to explain blockchain technology and the widely used methodologies for blockchain interoperability in supply chains. Then, four real-case blockchain use cases in supply chains from different industry segments are analysed in terms of their technical capabilities addressing interoperability concerns. Finally, we discuss results of use case analysis based on the comments of interviewees. The analysis reveals that REST-APIs with a common interface and GS1 standards are very useful to integrate with blockchain applications in supply chains for mass adoption.

Keywords: blockchain interoperability, supply chain, use case, API, blockchain ecosystem

1 Introduction

Big data is dramatically revolutionising today's supply chains (Emrouznejad, 2016). As big data becomes a larger and more user-friendly asset, supply chains are structured to be more data-driven for better service operations management (Charles and Emrouznejad, 2019; Charles and Gherman, 2019). Vast amounts of data are used in supply chains; they can be surrounded by structured/unstructured data, and decentralised and connected data streams (Emrouznejad and Marra, 2017). As a decentralised, ledger-based technology, blockchain technology plays a critical role in managing such big data to reduce risks, increase efficiency and visibility, and maintain transparency across end-to-end supply chains (Kayikci, 2021).

Blockchain is a digital data management infrastructure for big data that is both stable and flexible (Deepa et al., 2020). Many public and private blockchain applications with varying features have been developed since Bitcoin was launched in 2009. As companies develop blockchain solutions, they are increasingly concerned about the proliferation of blockchains, the linking of blockchain applications developed by several providers, and legacy systems, the fear being of locking up solutions too early (Lacity et al., 2019). For this reason, blockchain technology must develop standards and multi-channel information exchange protocol (Dhuddu and Mahankali, 2021). Blockchain technology, like any other evolving technology or platform, has several technical components and factors in order to operate efficiently (Wilkie and Smith, 2021). In the present context, there are several blockchain applications that address supply chain challenges and utilise existing blockchain platforms, such as Ethereum, R3 Corda, Hyperledger Fabric. The key concern in having blockchain-as-a-service (BaaS) architecture for mass adoption is the access, use, transfer and interpreting of data cohesively between different versions of platforms in a heterogeneous blockchain landscape (Deng et al., 2018; Koens and Poll, 2019; Syahputra and Weigand, 2019). Since a single blockchain network cannot meet all the needs for any given business transaction, multiple networks will need to collaborate to offer unique value. This is often referred to as interoperability.

The exchange of information for different blockchain transactions, or the use of information by different blockchain providers, necessitates an important interoperable architecture (Dutta et al., 2020). As the number of blockchain applications in the supply chain rapidly increases, companies prefer blockchain platforms that they can use without limitation in external collaboration options in the future. Therefore, interoperability is a critical concern for decision-makers interested in building blockchain solutions (Valle and Oliver, 2020; Belchior et al., 2021). Interoperability is an important element in the maximisation of efficiency and effectiveness when working with various public and private blockchain systems as well as non-blockchain systems together.

This chapter provides an insight into blockchain interoperability in supply chains for mass adoption. A three-step approach is applied through conducting a literature review of blockchain technology and commonly used methodologies for blockchain interoperability, analysing four blockchain real-life use case applications in supply chains that address interoperability concerns and mass adoption, and discussing results of the analysis based on the comments of interviewees. The rest of the chapter is structured as follows: Section 2 gives a broad overview of blockchain technology and its application in supply chains. Then in Section 3, the context of blockchain interoperability is explained in terms of data interoperability standards and cross-chain interoperability. Section 4 provides insights into blockchain interoperability and mass adoption using four blockchain use cases in the supply chain. The chapter ends with conclusions and future research directions in Section 5.

2 Scope of Blockchain Technology

2.1 Blockchain Definition

Blockchain technology is a distributed ledger technology. It is simply a digital database of transactions used by an extended network to record, share and synchronise without having central authority (Subramanian et al., 2020). Each transaction included in blockchain gets encrypted with its own key pair and linked to the previous and next transaction chronologically. Groups of transactions are blocked together, named the block; this contains transactions, data and references to the previous blockchain (creating the chain), shown in Figure 1 (Nakamoto, 2008). Every block with its own hash (digital fingerprint) is added to the next one, together with the timestamp, forming an unalterable chain. Blocks to be added to the blockchain must be achieved through consensus.

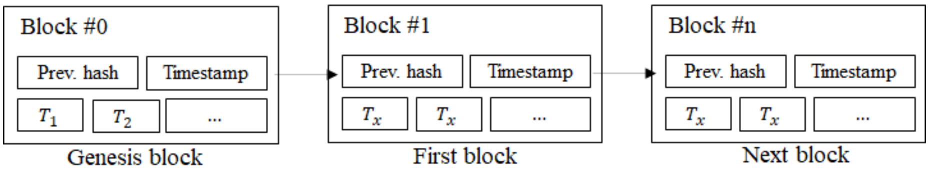

Figure 1: Blockchain structure

Source: Authors

2.2 Blockchain Types

Not all blockchains are the same. There are four different types of blockchain systems (Subramanian et al., 2020): public blockchain, private blockchain, consortium blockchain, and hybrid blockchain. Each type of blockchain meets specific objectives and requirements:

(i) *public blockchain*, also known as a permissionless blockchain, is the most used blockchain system type. Nobody requires permission to join, interact with, or forge consensus. This blockchain is an open, decentralised, secured, and immutable ledger system. However, the consensus efficiency is very low and the transaction speed is very slow. A transaction is recorded anonymously on the blockchain, but is transparent to anyone. Therefore, these are often ideal for operating and managing digital assets/currencies. Bitcoin, Ethereum, Litecoin are the well-known examples of a public blockchain.

(ii) *private blockchain*, also known as a permissioned blockchain, is a closed and either partially or completely centralised blockchain system type. Only validated participants can join a network and only through an authentic and verified invitation. A single trusted central organisation has authority over the network and it establishes rules dictating network participants who can see, read, write or validate transactions on the blockchain. Furthermore, this organisation has the right to override, edit or delete transactions on the blockchain. This type of blockchain is highly efficient as verification is done by the owner of blockchain network. However, it is difficult to align different organisations to the same blockchain. Hyperledger Fabric, Ripple, MultiChain are typical examples of a private blockchain.

(iii) *consortium blockchain*, also known as a federated blockchain, is a partially decentralised, semi-private blockchain system type. This is governed by a group of organisations (consortium), rather than a single organisation, that shares the responsibilities of maintaining a blockchain. This blockchain is best suited for organisations that need both public and private blockchains. Only a few pre-selected organisations or nodes in the network have the right to authorise transactions and supervise the consensus process. Therefore, there is no single authority in control. IBM Food Trust is a typical application of consortium blockchain. Quorum, R3 Corda are well-known examples of a consortium blockchain

(iv) *hybrid blockchain*, which means controlled access and freedom at the same time, is a combination of the public and private blockchain. This blockchain combines the features of both types, although is not open to everyone, and still offers blockchain features such as integrity, transparency, and security. The system architecture is fully customisable; the participants can decide who can participate or which transactions are made public. This provides the best solution from both public and private and ensures a company to work with its stakeholders in the best possible way. Dragonchain, XinFin, Libra are typical examples of a hybrid blockchain.

2.3 Evolution of Blockchain Ecosystem

Blockchain technology has evolved over the years and its evolution can be divided into three eras, as shown in Figure 2:

(i) *Blockchain 1.0 era:* The first-generation blockchains started with the emergence of Bitcoin in 2009.This was the first blockchain application and dominated for the first six years (Lacity et al., 2019). The public blockchain applications enabling digital currency transactions emerged in this era; however, they had multiple drawbacks, including efficiency and scalability. The blockchain ecosystems were separated in this era, meaning that there was no integration between different blockchain systems, so no interoperability.

(ii) *Blockchain 2.0 era:* The second-generation blockchains began in 2015 with the launch of Ethereum, a decentralised platform that allowed companies to use smart contracts to build a set of applications in supply chains (Lacity et al., 2019). The private blockchain emerged in this era, but they did not meet every use case requirement. There was only limited integration between blockchain ecosystems, so there was limited interoperability based on smart contracts.

(iii) *Blockchain 3.0 era:* The third-generation blockchain had a less identifiable launch, but the term is used to describe numerous applications including improving scalability, interoperability, security, privacy, resilience and sustainability (Ackermann and Meier, 2018; Lacity et al., 2019). The Blockchain 3.0 applications aimed at seamless integration across multiple public blockchains (Bitcoin and

Ethereum), multiple private blockchains (Hyperledger Fabric and R3 Corda), public and private blockchains (Ethereum and Hyperledger) and blockchains with legacy systems (Ripple and SWIFT).

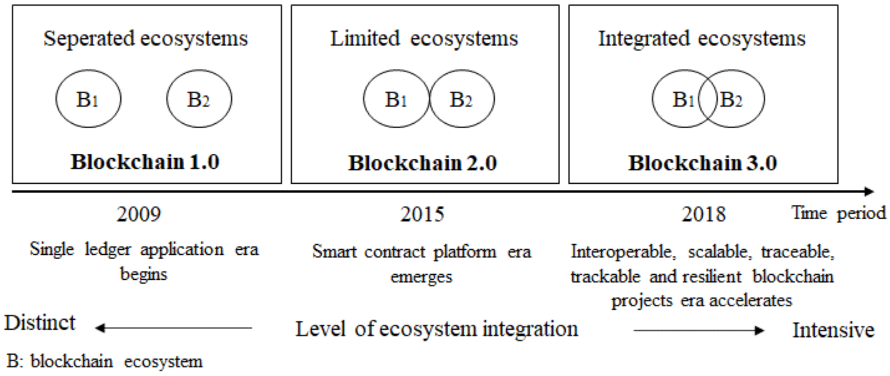

Figure 2: The evolution of blockchain ecosystem

Source: Authors

Organisations are willing to implement blockchain technology in their ecosystems. However, the technical complexities in building, operating, and maintaining blockchain infrastructure result in creating isolated systems and not allowing full integration between different blockchain ecosystems. These constitute obstacles to the mass adoption of blockchain technology. BaaS vendors develop and deliver solutions to support organisations to overcome interoperability barriers in using this technology. For that reason, Blockchain 3.0 has further expanded to enable the multi-chain future, especially in 2021. Cross-chain interoperability solutions are being developed with new decentralised protocols such as Polkadot, Cardano, Kusama and more. Also, blockchain markets and use cases like DeFi (Decentralised Finance), NFTs (non-fungible tokens), and decentralised applications have grown extensively. In addition, the development of interoperable, seamlessly integrated, automated, decentralised blockchain technology also adds incredible value to the capabilities of the Web 3.0 Internet, the next generation of the Internet. It is expected that the future will see the creation of fully integrated blockchain applications, ensuring seamless interoperability as the next generation blockchain.

2.4 Blockchain in Supply Chains

Blockchain technology is increasingly being adopted in dispersed supply chain networks, with many participants since the launch of private blockchains (Dujak and Sajter, 2019). In particular, an increasing amount of digital data is generated in supply chains every day, as more and more customers tend to buy online (Deepa et al., 2020); therefore, big data and blockchains need to work together to create more opportunities and better service operations. Blockchain technology is expected to increase transparency and accountability for the streams of goods, commodities, money and information between parties to enable more integrated, flexible, reliable, secure and efficient value chains, while providing an immutable, auditable record of activities along the end-to-end transaction journey (Subramanian et al., 2020, Kayikci, 2021). Blockchain enabled supply chains can have the potential to simplify processes, identify counterfeit products, facilitate proof of provenance, enhance track and traceability (e.g., ensuring refrigerated goods are kept within a consistent temperature range), reduce paperwork processing, and operate the Internet of Things (IoT), while reducing costs and minimising risk (Casino et al., 2019; Tijan et al., 2019; Wang et al., 2020). Indeed, the inherently “anti-authoritarian” nature of blockchain technology contributes to sustainability in a supply chain network and across different supply chain networks (Kayikci, 2021).

Figure 3 shows a blockchain ecosystem with participants in the food industry where all network partners, including farmers, cooperatives, manufacturers, distributors, transporters, retailers, and customers as well as interrelated institutions such as banks, insurance services, certification bodies and governmental authorities (e.g., customs, tax), form a consortium in their respective ecosystem running on the blockchain platform. Here, technical alignment and collaboration within supply chain partners is essential. In order to reveal the real blockchain potential in supply chains, seamless data exchange within and between ecosystems is required (Pan et al., 2021). The data exchange within an ecosystem refers to the intra-ecosystem relationship and seamless interoperability between the same network partners along the vertical supply chain, while data exchange between ecosystems denotes the inter-ecosystem relationship between different network partners along the horizontal supply chain. The existing blockchain use cases in supply chains from manufacturing, healthcare, retail, transportation, and food to other industries, show that most supply chain consortia operate on private, consortium or hybrid blockchain systems (Subramanian et al., 2020).

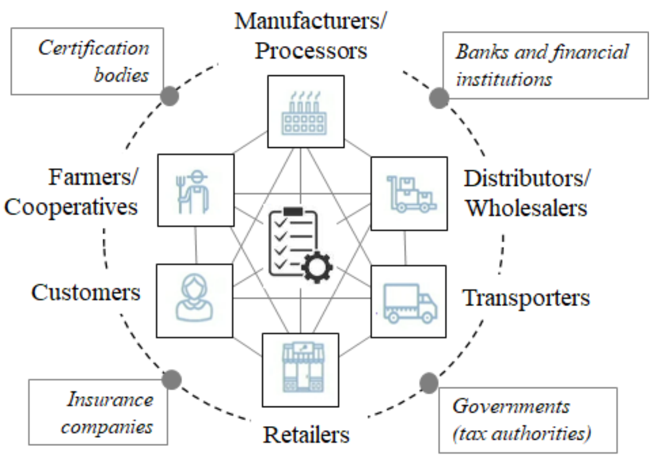

Figure 3: A blockchain ecosystem in supply chain

Source: Authors

3 Blockchain Interoperability

Blockchain adoption is on the rise across supply chains of different industries. However, the lack of interoperability standards is a major obstacle to mass adoption (Casino et al., 2019; O'Leary, 2019). More and more commercial enterprises build and implement private, consortium or hybrid blockchains (Wilkie and Smith, 2021), which create often closed ecosystems. They use multiple data standards and protocols that isolate blockchains in their respective environments. Due to the nature of the business, blockchain networks require integration between both disparate blockchain and non-blockchain ecosystems. In a large-scale multi-chain environment, one of the important issues is to integrate different ecosystems together to sustain cross-chain information sharing and seamless secure data exchange between those ecosystems (Li et al., 2020; Belchior et al., 2021). This issue refers to interoperability. Figure 4 illustrates the blockchain interoperability for three cross-sectorial ecosystems in food supply chains, where two are the blockchain ecosystem and the third is the non-blockchain ecosystem. In an ecosystem, both *inter-blockchain interoperability* (in order to integrate blockchain ledger and legacy systems of partners) and *intra-blockchain interoperability* (for the purpose of cross-chain interoperability) is required *for blockchain-to-blockchain* and *blockchain-to-non-blockchain* seamless communication..

Interoperability simply refers to the capability of computer systems to exchange and use information, as well as to transfer an asset between two or more systems while keeping the status and uniqueness of an asset consistent (WEF, 2020). Interoperability standardisation can create commonly agreed blockchain terminology. Implementation of common standards and protocols in blockchains can provide scalable interoperability and integration with different blockchains and non-blockchain systems. Resolving collaboration and cross-chain interoperability problems between public, private, consortium and hybrid blockchains can open the way to a hyper-connected world (Yaga et al., 2018). The general definition of blockchain interoperability provided by the US National Institute of Standards and Technology (NIST) is:

> "An interoperable blockchain architecture is a composition of distinguishable blockchain systems, each representing a distributed data ledger, where transaction execution may span multiple blockchain systems, and where data recorded in one blockchain is reachable and verifiable by another possibly

foreign transaction in a semantically compatible manner". (Hardjono et al., 2019, p. 4)

Traceability is a challenge of a multiple stakeholder and multiple networks.The seamless data exchange between different blockchain systems is crucial to the success of every business. In this sense, it is necessary for blockchains to be standardised to be future-proof (Belchior et al., 2021). This would allow parties to speak the same language, so that they can interact and transact with other existing or upcoming blockchain networks, as well as incorporate and share common capabilities and feature sets related to consensus models, transactions, and contract functionalities (Jabbar et al., 2020). Blockchain interoperability allows blockchain systems to communicate with each other without the help of intermediaries (Ackermann and Meier, 2018; Dhuddu and Mahankali, 2021).

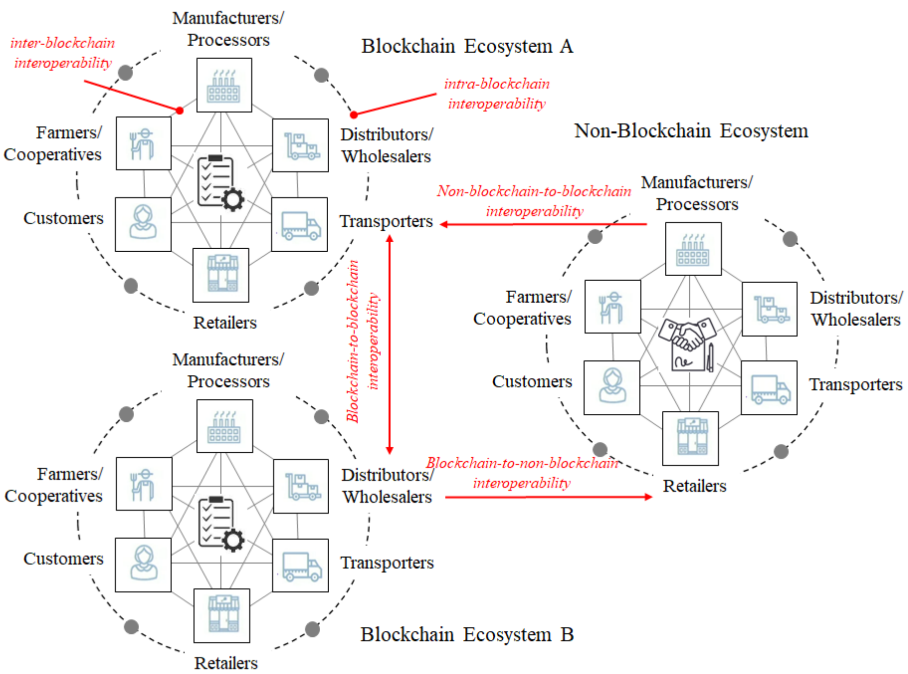

Figure 4: Blockchain interoperability for different ecosystems in supply chains
Source: Authors

3.1 Data Interoperability Standards

Data stored or referenced by blockchain supply networks can be configured for shared communications and interoperability through the use of standards and protocols. Different data standards are developed to solve the interoperability problems in the blockchain world. The most commonly used open supply chain standards for blockchains are the GS1 global traceability standard (GS1, 2017) and ISO (the International Organization for Standardization) open standards for blockchain and distributed ledger technologies (ISO, 2016). These impact parties in supply chains for sharing business value in a standardised way (Keogh et al., 2020) and enable interoperability between them by creating a common set of rules for identification, data capture, data sharing, and data usage (GS1, 2017). In addition to these two standards, UN/CEFACT (United Nations Centre for Trade Facilitation and Electronic Business) launched a project to develop a strategy for the use of blockchain technology and created the UN/CEFACT standard with Supply Chain Reference Data Model (SCRDM) for trade facilitation (UN/CEFACT, 2019). Also, some associations are developing blockchain industry standards for supply chains and logistics. The International Port Community Systems Association (IPCSA)[1] started a blockchain bill of lading initiative with the cooperation of Alibaba and LOGINK; this aims to standardise blockchain applications for logistics and e-commerce to facilitate global port system operations and eliminate paperwork. The Blockchain in Transport Alliance (BiTA)[2] established a common framework and industry standards for DLT and blockchain applications/solutions in the transportation, logistics, supply chain and freight industry. Lin et al. (2019) developed a blockchain-based traceability system for food safety using joint GS1 and ISO interoperability standards called EPCIS (Electronic Product Code Information Services). This system aims to enable a management architecture for standard data exchange and item-level tracking from blockchain and non-blockchain ecosystems where the traceability system can overcome potential data problems. According to Valle and Oliver (2020), the developed ISO/T3-307 standard might provide better accessibility and alleviate interoperability issues by representing a tool to disseminate innovation and harmonise different protocols. Kan et al. (2018) proposed an inter-blockchain communication model for multi blockchain architecture.

GS1 standards enable blockchain consortia to seamlessly interoperate; the network of supply chain stakeholders depends on industry’s commitment to standards. The GS1 Standards System is an integrated global standards package that provides supply chain visibility by accurately identifying, capturing and sharing information about products, parties, locations, assets and services. In this sense, the GS1 standards support the core service concepts of identity, capture, and share to encourage organisations to improve traceability for the benefit of all participants in the global supply chains (GS1, 2017; Jabbar et al., 2020).

- The *GS1 identity keys* are used in six areas (GS1, 2017):
  - (i) Company: Global GS1 Company Prefix; Global Location Number (GLN);
  - (ii) Product: Global Trade Item Number (GTIN); Serialized Global Trade Item Number (EPC*/SGT);
  - (iii) Location: Global Location Number (GLN);
  - (iv) Logistics: Serial Shipping Container Code (SSCC); Global Shipment Identification Number (GSIN);

[1] https://ipcsa.international/initiatives/logistics-visibility-task-force/
[2] https://www.bita.studio/

  - (v) Assets: Global Individual Asset Identifier (GIAI); Global Returnable Asset Identifier (GRAI);
  - (vi) Services and other: Global Service Relation Number (GSRN); Global Document Type Identifier (GDTI).
- The *GS1 capture keys* are categorised in two classes (GS1, 2016):
  - (i) Barcode, which contains UPC/EAN, Code 39, Code 128, Code 16K, Code 49, PDF 417, Data Bar, DataMatrix, QR Code, Aztec Code and MaxiCode;
  - (ii) Electronic product code, which contains only EPC (UHF, HF Gen2) / Radio Frequency Identification (RFID).
- The *GS1 share keys* are divided into three data exchange types (GS1, 2017; Jabbar et al., 2020):
  - (i) visibility event data from physical/digital object: EPCIS and Core Business Vocabulary (CBV);
  - (ii) transactional data of objects: GS1 EDI (GS1 XML, GS1 EANCom, eCom);
  - (iii) master data: Global Data Synchronization Network (GDSN), GS1 source, GS1 smart search, GLN service.

3.2 Cross-Chain Interoperability

In practice, blockchain solutions are formed around existing smaller and even closed ecosystems. Therefore, they often remain disconnected from each other, like islands with their own communities, unable to exchange information or values with the outside world. However, the global supply chains intersect multiple types of ecosystems and require blockchain to blockchain as well as blockchain to non-blockchain integrations (Pillai et al., 2020). Cross-chain interoperability not only increases the scalability of the blockchain, but also opens up the channel of value circulation between different chains. That means that blockchains can talk to each other and one can read the other's state. Two types of data are used for interoperability (Buterin, 2016; Belchior et al., 2021): digital asset exchange and arbitrary data exchange. Digital asset exchange provides the ability to transfer and exchange anything representing value (e.g., cryptocurrencies, non-fungible tokens) originating from different blockchains, whereas arbitrary data exchange provides the ability to use data (e.g., making payment to a supplier) on one blockchain platform to affect state changes on another. This refers to the capacity to make advanced blockchain to blockchain Application Programming Interface (API) calls by extending to the smart contract code on a blockchain that directly verifies the consensus certainty of events on other blockchains. The most use cases in supply chains use arbitrary data exchange (WEF, 2020).

In order to achieve blockchain interoperability, some approaches were developed in the literature from a technical perspective. Interoperability approaches across public blockchains are well-known and widely used. They were categorised under three classes (WEF, 2020):

(i) *Oracle*: this approach uses a tool known as an oracle to get data and alike to send data; oracle employs smart contracts to add actual data (e.g., temperatures, humidity, prices) onto blockchains for business process automation (Beniiche, 2020). This method can be easily implemented, especially in a non-blockchain environment (Mammadzada et al., 2020). In fact, oracles do not create a real blockchain to blockchain interoperability; they combine non-blockchain systems to make a blockchain interoperable with those systems (Wilkie and Smith, 2021).

(ii) *API gateway*: this organises several APIs and essentially acts as an intermediary to communicate between two or more blockchain platforms/applications; however, it still requires cross-authentication between nodes. An API is a piece of code that manages the access point to a server, and rule developers must follow this to interact with a database, library, software tool, or programming language (WEF, 2020). Creating and implementing an API gateway is easier than other interoperability approaches (Wilkie and Smith, 2021), also, an API gateway centralises trust in the API operator.

(iii) *cross authentication*: this provides cross-chain interoperability between both different blockchain to blockchain and blockchain to non-blockchain systems. Cross authentication covers three methods as follows (Buterin, 2016):

- *Notaries* (both digital asset and arbitrary data exchange): the simplest way to facilitate most cross-chain operations is to use an intermediary trusted entity (a third-party) or group called a notary scheme/a set of notaries (also known as one-way pegs or two-way pegs) that confirms the status of an interactive blockchain to enable operations (Buterin, 2016). The notaries come to an agreement through a consensus algorithm. Notaries follow a centralised architecture to ensure cross-chain interoperability (Kannengießer, 2020). The disadvantage of this system is the third-party dependency; the system needs the active participation of a trusted and centralised entity (Dilley et al., 2016). Therefore, notaries provide a low level of decentralisation. This method is also proven to a limited extent in few solutions (Koens and Poll, 2019). Liquid using federated pegged sidechain is a primary solution in this category (Jabbar et al., 2020).
- *Relays* (both digital asset and arbitrary data exchange): a relay scheme, also known as a sidechain, secondary chain or satellite chain, is a mechanism for two existing blockchains to interoperate (Belchior et al., 2021), which is used in many blockchain interoperability solutions. This method provides a high level of decentralisation (Pillai et al., 2020). Although many interoperability solutions expect to expand functionality, this method has not been well proven. The most prominent efforts in this category are Cosmos, Polkadot, and ChainLink (Jabbar et al., 2020).
- *Hash-locking* (only digital assets exchange): a hashed time lock, also known as an atomic swap, is the most practical technical approach to blockchain interoperability and provides a high level of decentralisation. This method is proven technically in several solutions; however, it is the most limiting solution in terms of functionality. A hash time locked contract (HLTC) is a time-bound conditional blockchain-based payment that uses hashlocks and timelocks to require the receiver of a payment to either acknowledge receiving the payment prior to a deadline or forfeit the ability to claim the payment, therefore returning it to the payer. HTLCs allow cross-chain atomic swaps and fully funded bi-directional payment channels between assets on certain types of blockchain.

Interledger Protocol and ARK Core Series are the most prominent solutions of hash-locking.

The industrial solutions (e.g., Polkadot) that enable cross-chain operations are developed based on the aforementioned interoperability methods and act as a bridge to transfer digital assets and/or arbitrary data from one blockchain ecosystem to another. The chains may have different governance models, protocols, rules, and communities, but the bridge provides a cohesive way for both parties to interoperate securely. There are different designs for the bridges depending on the selected methodology. As a summary, they can mainly be divided in two categories: "trusted" or more centralised bridges (Notaries) based on trust or federation, and "non-trusted" or more decentralised bridges (Relays and Hash-locking) without having a third-party. The trusted bridge depends on some form of central authority that establishes trust for users to operate within a particular third-party app or service. The non-trusted bridge does not need a legal entity or authority to be trusted, but rather relies on the mathematical logic embedded into the code, enforced by the technology and/or incentive mechanism behind the system. Since 2021, many industrial solutions based on such interoperability methods have been developed, notably in line with the foundation of Web 3.0 Internet technology. In particular, the non-trusted types of interoperability are often preferred in blockchain ecosystems. In the next section, we analyse these interoperability methods with different use cases.

4 Blockchain Mass Adoption

4.1 Blockchain Use Cases in Supply Chains

In this section, in light of the interoperability methods explained previously, we want to analyse some of the real-life blockchain use cases to understand their potential for blockchain interoperability and mass adoption. A total of four blockchain use cases from different industry segments were selected, and the procedures are documented through multiple interviews.

Table 1: Data collection

Use case company	The person interviewed	Industry area	The duration of Interview	Secondary data used
UC-1	Founder (Interviewee 1)	Food and agriculture	55 minutes	News articles, public interviews of founder
UC-2	Managing Director (Interviewee 2)	Recycling	40 minutes	News articles, public videos and interviews
UC-3	Business Development Representative (Interviewee 3)	Logistics/ Shipping	45 minutes	YouTube videos, news articles, press releases
UC-4	Chief Technology	Textile,	50 minutes	LinkedIn article, public

	Officer (Interviewee 4)	Garment & Accessories	podcasts, press releases

Source: Authors

Data collection: the selection process of use cases was made due to market size, recognition, and presence in the global supply chain ecosystem. First, the ten most appropriate use cases were identified based on the requirements of this chapter. We contacted them via email and LinkedIn to invite them for an interview: four of them agreed to participate in the interview. The selected use cases were from the network of the first author. The interviews were carried out online on an agreed day, and the duration of each interview was less than an hour. The interviews were recorded with the permission of the participants. The interview questions were open-ended to understand interoperability issues as well as mass adoption in terms of use cases; a checklist was used as a guide to ensure content comparability. We mainly talked with companies about the technical aspects of their solutions, such as the blockchain framework used, the features and functionality of blockchain ecosystems, the interoperability model, data standardisation, and mass adoption capabilities. After the interviews were completed, the recorded videos were coded and summarised; in this way, the primary dataset based on each use case interview was prepared. In addition, secondary data about each use case from different sources, such as news articles, press releases, company presentation and so on, were collected to use in this section. Table 1 shows the details of the data collection.

Data analysis: the data collected during the interviews and from other sources were analysed for each use case. The authors read each text several times to examine the whole context according to the business environment, the purpose of blockchain use, interoperability model and data standards. Table 2 denotes the analysis of blockchain use cases. The details of use cases are explained as follows:

UC-1 is a blockchain platform powered by the Corda framework to provide end-to-end traceability, cold chain monitoring (temperature, humidity) and organic certification for food products in the food supply chain. The blockchain platform is based on a consortium blockchain and uses most food related data standards for GS1, EPCIS & CBV, and GTS and APIs and relays approaches as interoperability methods.

Table 2: Analysis of blockchain use cases in supply chains

#	Business industry	Blockchain framework	Blockchain functionality	Inter-operability model	Data standards	Mass adoption
UC-1	Food	Corda (consortium blockchain)	Food traceability; cold chain monitoring; organic certification	Relays; APIs (CorDapp)	GS1, EPCIS & CBV, GTS 2.0	Low
UC-2	Recycling	Hyperledger Sawtooth (consortium blockchain)	Origin tracking; battery passport	Oracle; HTLC; API Gateway	ISO, GS1	Medium
UC-3	Logistics/	Hyperledger	Trade	Oracle;	UN/	Medium

	Shipping	Fabric (private blockchain)	facilitation; workflow automation; vehicle monitoring and tracking; freight payments	HTLC; API Gateway	CEFAC, GS1	
UC-4	Textile, Garment & Accessories	Ethereum/ Quorum (private blockchain)	Origin and ownership tracking; counterfeit detecting; original certification	Oracle; HTLC; APIs	GS1	Low

Source:Authors

UC-2 is a blockchain platform powered by a Hyperledger Sawtooth framework to provide origin tracking (source) for vehicle batteries and lithium-ion batteries in the electronics recycling industry involved in the battery recycling supply chain. It also tracks recycling processes to generate a battery passport. A recycler can use the blockchain platform to easily separate strings for use from one battery to another without losing its originating data. This platform is based on a consortium blockchain and uses ISO and GS1 standards as data standards, and oracle, HTLC and REST APIs as interoperability methods that simplify the creation and transmission of transactions and batches to Sawtooth network nodes. This blockchain platform aims to bring relevant companies in battery recycling ecosystems together to increase higher efficiency, engagement and productivity in battery recycling operations. In addition, the platform provides a consensus mechanism built into the battery recycling supply chain network.

UC-3 is a blockchain platform powered by a Hyperledger Fabric framework to coordinate the business network for all multimodal shipment activities among shippers, transport providers, ports and terminals, ocean carriers, government authorities, customs brokers, and more. The information shared by each participant on the platform can be tracked, recorded and managed throughout the shipment's journey. This platform is used to facilitate trade, automatise workflow, track logistics operations (vehicle monitoring and tracking) and payment processes (automated freight payments, shipping cash flows). This blockchain platform operates in a private blockchain ecosystem and uses oracle, HTLC and API gateway approaches for interoperability, where REST APIs integrate into the in-house systems (e.g., ERP, TMS) of participants. UN/CEFACT and GS1 data standards are used for data exchange.

UC-4 is a platform powered by an Ethereum/Quorum framework to enable origin tracking, counterfeit detecting and original certification of luxury components and products for textiles, garments and accessories. The blockchain platform is based on a private blockchain, so that the participants from processors to end-users can track real-time information on origin and ownership, authenticity, maintenance and equipment. The platform uses oracle, HTLCs and APIs as interoperability approaches, also GS1 standards as data standards.

4.2 Discussion

In this section, the results obtained from the interviews are discussed by quoting the interviewees. The most used blockchain platforms operate on open-source BaaS frameworks; these have different technical competence and interoperability capabilities. Therefore, the use cases of the platforms examined in this section have different infrastructures and implementations. All interviewees acknowledged "interoperability is crucial to business success", but although "interoperability is not a blockchain-specific concept, it requires coordinated standards to allow data exchange in a secure and validated manner" (interviewee 1). Particularly, interviewee 2 and interviewee 3 emphasised "the interoperability capabilities provide seamless, user-friendly experiences for participants across different platforms in the wider blockchain ecosystems". Furthermore, interviewee 4 added that "incompatible technologies, lack of transparency and possible confusion cause friction and lead to inefficiency for their business".

In addition, interviewees highlighted the importance of mass adoption to keep their business going. This also indicated that "the rate of mass adoption depends on the level of interoperability that aligns with the capabilities of their blockchain platforms" (interviewee 2 and interviewee 3). It can be summarised that non-interoperable blockchain ecosystems will be siloed and disconnected from each other, operating side by side without communication and transaction, while interoperable blockchain ecosystems ensure multiple participants from separate blockchain networks to interact without spending resources to translate received information and experience downtime.

All interviewees believed that using APIs with other cross-chain interoperability methods can enable blockchain use cases to have data transparency and end-to-end visibility throughout all stages of the supply chain lifecycle, from suppliers to retailers, and facilitate communications among them. It is acknowledged that "interoperable blockchain systems allow information to be easily processed and sent a response accordingly" (interviewee 1 and interviewee 3), also "interoperability is conceptually simple and can be solved relatively easily with APIs" (Interviewee 2). However, interoperability across different blockchains is more extensive and complicated, as blockchain frameworks (e.g., Ethereum and Hyperledger or Ethereum and Corda) use different hash algorithms and consensus protocols; even these may differ when new versions arrive. On the other hand, the use cases agreed that using a one-size-fits-all standard for interoperability is not suitable for blockchain platforms. Each use case has different requirements to meet and the use of a single standard cannot respond to this. On the other hand, setting a single standard would cause important time delays and hinder the critical innovations required. Therefore, it is believed that "establishing open standards can allow all parties in a supply chain to contribute naturally and create a single, state-of-the-art public blockchain" (all interviewees). Nevertheless, interviewee 3 contributed that "the standards need to be as simple as possible to integrate the solutions to each other and to release new blockchain based business models".

In addition, interviewees believed that "their participants can leverage interoperability to operate with greater confidence and less risk of obsolescence, thereby improving mass adoption”. The analysis of blockchain use cases showed that the rate of mass adoption ranged between low and medium, depending on the current level of interoperability. As a final remark, interviewees noted “the implementation of REST-APIs with a common interface and GS1 industry standards contributed to interoperability for mass adoption in the supply chain”.

The use case analysis showed that different interoperability methodologies are used, such as relays, oracles and HTLCs. This is mostly in line with the capabilities of the respective blockchain frameworks (ledger technologies) to exchange value or information based on existing technologies. This enabled different stakeholders in blockchain ecosystems to access blockchain data with different read access levels. However, under these circumstances, no blockchain use case will achieve full mass adoption. More decentralised protocols must be used to communicate with the outside world. In particular, the siloed nature of today’s blockchain networks cannot be aligned with the principle of decentralisation and reflects the partition of the current centralised Web 2.0 Internet. This also means that blockchain technology is not yet mature and there is still room for improvement in this technology in terms of interoperability. As a result, we can say that the next generation blockchains with the use of a trusted, secure and decentralised Web 3.0 Internet will be more capable and efficient in providing seamless interoperability.

5 Conclusions

There is an increasing need for advanced technologies to overcome the hype and mature into useable technologies adopted on a large scale for economic benefits, while the growth of big data increases the need to securely manage, store and exchange data across supply chains. Blockchain is one of those technologies used to scale up. However, it still has many technical capability shortcomings due to its immaturity. One important technical challenge is the lack of interoperability between different blockchain systems, often seen as the biggest deterrent to mass adoption. The literature review and use case analysis reveal that interoperability is a critical element for the existence and sustainability of blockchain-based platforms and business models. In the short term, this could mean transferring value from one organisation’s legacy system to another organisation’s blockchain ledger, while in the long term, it could mean trading between different types of blockchain as well as non-blockchain and other legacy systems. There are some industrial solutions that use interoperability methodologies to solve interoperability challenges and they are still in development. Few bridges can provide a good level of interoperability, but there is still no solution for full interoperability that can integrate every kind of blockchain ecosystem. It can be said that the sooner the blockchain matures, the higher the rate of mass adoption will be.

Today’s supply chains are heavily influenced by big data. Blockchain technology is the ideal solution for the many service operation challenges faced by data-driven supply chains. The respective stakeholders join a blockchain platform to seamlessly exchange massive amounts of data throughout supply chains. Data exchange can take place in the vertical integration of a blockchain ecosystem. However, no blockchain network can exist without the horizontal integration of other ecosystems, otherwise such isolated blockchains will sooner or later disappear from the market. Therefore, the blockchain platforms should be designed to be as interoperable as possible to transfer a digital asset or arbitrary data seemingly from one blockchain ecosystem to another; this is because the future of blockchain will evolve on multi-party and multi-chain due to current business challenges. In the future, more research is needed on blockchain interoperability highlighting the multi-chain aspect. This could include the maturity assessment of blockchain interoperability in multi-party and multi-chain ecosystems, making new implementation decisions on existing blockchain solutions in terms of interoperability for the development of new multi-chain blockchain use cases, or checking the interoperability capabilities of different ecosystems to decide on multi-chain collaboration.

This chapter has some limitations. First, the presented case analysis covered only four blockchain use cases. More use cases could be included in the analysis to understand the relationship between blockchain interoperability and mass adoption. Second, we analysed four blockchain use cases from different industry segments, and their ecosystems had no relationship with each other. This analysis could also be done for blockchain use cases belonging to different ecosystems, such as central complementary, supplementary or competitive ecosystems that are interrelated.

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