Chapter 14
Blockchain Integration Into Supply Chain Operations:
An Analysis With Case Studies

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ABSTRACT

Following the globalization initiated by containerization of logistics, supply chains might be due another revolution by the integration of the disruptive blockchain technology that addresses the current issues with the management of complex global supply chains. Blockchains are distributed digital ledgers that require no central authority to operate while offering a tamper-proof and transparent history of each transaction from the very beginning. Distributed nature of these ledgers ensure that every participant of the supply chain has access to trusted data. The industry has already begun experimenting with blockchain integration into their operations. For the majority of the organizations, however, these experiments stay in proof-of-concept stages or small pilot studies. In this chapter, the authors discuss the supply chain characteristics that make blockchain integration favorable, lay the groundwork for how blockchain can be used for supply chain operations and how it has been used so far.

INTRODUCTION

Supply chains are networks of independent organizations that create and deliver a product to a customer. These complex provenance networks often span multiple countries or even continents. Due to the sheer number of actors on a supply chain, organizations concern themselves only with their immediate links; the upstream actor they are buying from and the downstream actor they are selling to. Incidentally, no one organization has overall control of the whole network, but organizations have to manage their resources and capital to fulfill their niche on the supply chain.

DOI: 10.4018/978-1-7998-6650-3.ch014

Supply Chain Management is the collaboration and cooperation of resources, time, and capital of the organizations on the chain. There is a delicate balance between centralization that leads to efficient use of time and resources, and decentralization to deter opportunistic behavior and fraud (Azzi et al., 2019; Schmidt & Wagner, 2019). As mentioned above, supply chains are not centralized, so it is not feasible to think that organizations have adequate information about the provenance of their inputs below or they are liable to provide information to the parties above them. The lack of information causes wasted inventory space, uncertain delivery times and forces companies to plan with margins of errors that can lead to the bullwhip effect (Ivanov et al., 2018).

Blockchain technology became popular after it was used to power the cryptocurrency Bitcoin in 2008 (Nakamoto, 2008). Since then it has found many uses in other than the finance domain. The primary benefits of blockchain technology in the supply chain management context include: *transparency*, *traceability* and *decentralization*. Blockchain can be used as a tamper-proof, immutable ledger shared between all parties. Once adopted by the organizations on the supply chain, transactions between the participants can be committed to the blockchain with some consensus process verifying the legitimacy of the data. The transparency and traceability of the information go hand-in-hand with a permission system such that the owner of the data can allow access only to concerned parties. All parties along the chain including the customers at the end can verify the provenance of the product they get and confirm that it is not counterfeit, sourced with unethical or questionable labor practices or contaminated in some way.

The industry has been conducting pilot studies for blockchain integration to the supply chain including food (IBM, 2017) and logistics (Moise & Chopping, 2018) industries. The literature has also suggested extensible frameworks (El Maouchi & Ersoy, 2018) and targeted applications such as a counterfeit-proof electronics supply chain (Xu et al., 2019). Internet of Things (IoT) is another field that can highly benefit from the *digitization* and *interoperability* that blockchain technology provides. IoT encompasses devices that have network access, collect data and act autonomously. With the developments in big data and machine learning fields, there is apparent value in collecting data to optimize operations and make informed decisions.

This chapter presents supply chain basics and identifies potential issues with the current supply chain management solutions. Then, the usefulness of blockchain for supply chain management is presented. The drawback of blockchain integration is examined alongside common criticisms against the technology and a discussion about when blockchain is not the viable solution. Finally, use cases from real life and literature is given in detail and open questions, as well as future research directions, are reviewed. Preliminary information regarding supply chains and current problems with it are presented for the rest of the section.

Supply Chain

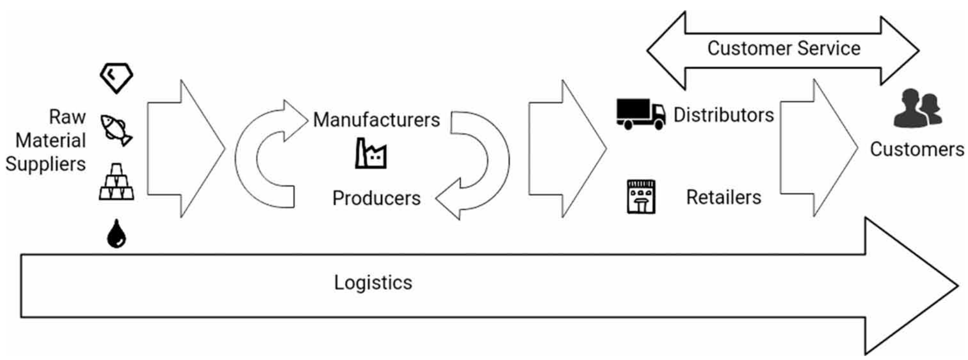
A supply chain is the collection of organizations that ultimately deliver value to an end customer. A typical view of a supply chain, also depicted in Figure 1, starts with the natural resources that suppliers provide for manufacturers, which are then built into components and finally into products for the consumer market, with distributors handling the flow throughout the network.

In order to deliver the final product, intermediate organizations interact with their suppliers, customers and logistics handlers, creating a material, component, information and capital flow in this network. It is important for the network to allow bidirectional flow to get feedback and handle refunds from the customers at each level and ultimately from the end user.

The modern supply chain operates at a global level. The globalization was initiated after shipping costs became negligible in terms of distance, causing production to be done on the cheapest lot with the cheapest labor instead of near resources or transport hubs (Levinson, 2008). Since procurement is done on a global scale, competition occurs on the global stage as well.

In the article, *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger* (Levinson, 2008), the author argues that the widespread adoption of the shipping container inadvertently caused the shipping costs to be negligible and kickstarted the modern global supply chains. This should not be mistaken with the *invention* of the shipping containers. Previous attempts to adopt containerization failed because the implementation was tried on just parts of the supply chain. For instance, the ship owners only implemented up to what made sense for their equipment. As a result, the next organization, down the line, had to deal with the non-standard logistics decisions of their supplier. Packing already packaged goods to yet another package and unpacking them at destination to sort through them caused the businesses to avoid containers. Yet, the benefits of the containers became apparent as the network effect led the whole supply network to support shipping containers; from the design of the ships to the docks and the packaging of the products. In short, the true potential of containerization was only realized when the "old ways" of the logistics side of the business were abandoned.

Figure 1. An overview of an end-to-end supply chain.



Does blockchain have the potential to disrupt the supply chain business, similar to what shipping containers did previously? Blockchain brings cryptocurrency connotations alongside, which is led by the success story that is Bitcoin, but also malicious actors or frauds such as Onecoin (Department of Justice, 2019). The story of how a company achieved a 289 percent increase in their share price only for it to crash back down in the same day, just by adding *Blockchain* to their name (Shapira & Leinz, 2017), which is indicative of the hype surrounding the technology. Another alternative to consider is this phase where businesses have not figured out how to utilize the potential of blockchain, similar to how businesses in the 1950's, who did not understand containerization, thought shipping containers were unnecessary or tried to keep the status quo for their own interests.

One of the most disruptive technologies the world has witnessed is the Internet (Babich & Hilary, 2020) which draws parallels from the dot-com bubble of the 1990s and the blockchain. This new and exciting technology might also go through the similar phases; hype, rapid adoption causing a bubble, then the crash and then stabilization. Following the dot-com bubble, the Internet is now the familiar way of doing business. Blockchain may go through similar phases and find a stable niche to fill once its benefits and drawbacks get properly figured out. Surveys conducted on adopters of blockchain from industry (e.g. Pawczuk et al., 2020) claim that the current phase of blockchain sentiment has already reached stabilization.

Problems with Supply Chains

Logistics under information asymmetry entail coordination, while keeping the international stage in mind where laws and ideologies differ across the borders during the journey of a product (Liu & Li, 2020). Any inefficiency during planning the operations results in non-optimal use of inventory and production facilities (Liotine & Ginocchio, 2020). This is directly tied to how operations of an organization are separated across the globe (Zhang, 2019). Furthermore, industry experts point to procurement and inventory costs as the main culprits to optimize using data driven long term planning (Kaçan, 2019). Supply chains with tiers of manufacturers, retailers and logistics entities are striving to create value for their organization. The paper-and-pen record keeping and the trail of hardcopy documents including invoices, certificates and bills of lading causes an environment where information is transient. Besides, the scarcity of information allows malicious actors to tamper with the documents through forgery or "double-spending" and robbery of container contents (Kshetri, 2018). The lack of comprehensive information has indirect consequences as well.

In competitive environments such as business negotiations, a negotiator tends to exploit the other party if there is an asymmetry between what two parties know of each other's resources (Boles et al., 2000). This phenomenon has been tested under laboratory conditions within supply chain negotiations as well (Inderfurth et al., 2013). In that study, the authors explain that if one party withholds information and acts upon it within their full capacity, the exploiting party receives benefit with the expense of the rest of the supply chain including higher retail prices for the end customer. In order to disclose information, the suggested method is using *screening contracts*. However, these contracts are set up manually, which hinders the efficiency of the supply chain, especially considering the tendency to operate under Just-in-Time (JiT) approach. Furthermore, the authors have found through experiments that communication and mutual trust increases the supply chain performance, yet this trust is fragile. The root cause of the issue still lies in the cumbersome nature of doing business with paper-based document trails, which makes information sharing harder than information withholding.

The lack of trust in an environment with asymmetric information access and limited information flow dictates entities' behavior. Babich & Hilary (2020) argue that retailers and suppliers on a supply chain would like to drive the price to their benefit by providing skewed information. For instance, suppliers forecast lower production to decrease the apparent supply, driving the price up. Retailers, on the other hand, present artificially inflated demands by forecasting higher sales to get the suppliers to increase their stock, driving the supply up and the prices down. Ultimately, both parties are exploiting the lack of widespread information.

The Bullwhip effect is a direct cause of competition under asymmetric access to information between parties. This effect dictates that when the variance of the presented demand to the manufacturers is higher than the variance of the production capacity of said manufacturer, they cannot make optimal decisions. The effect causes inventory mismanagement, reduced quality in customer service and inefficient distribution of production facilities (Schmidt & Wagner, 2019).

To summarize, the issues regarding supply chains have been identified as:

1. Difficulty of tracking and tracing
2. Not enough deterrence against unethical behavior, corruption
3. Arduous coordination efforts due to globalization and paper-based documents

BLOCKCHAIN TECHNOLOGY FOR SUPPLY CHAIN MANAGEMENT

This section starts by covering fundamental properties of blockchain technology. Then, a detailed presentation on blockchain aspects in relation to supply chain operations is given. Finally, how supply chain operations can benefit, from blockchain integration alongside Internet of Things technology, is discussed.

Blockchain

A blockchain is a series of cryptographically connected data blocks. Each block contains a timestamp, nonce value, reference to the previous block and the list of new transactions. The reference to the previous hash as well as the nonce value ensure that the blockchain is a continuous state and cannot be tampered with. A simplified structure of the blockchain is given in Figure 2.

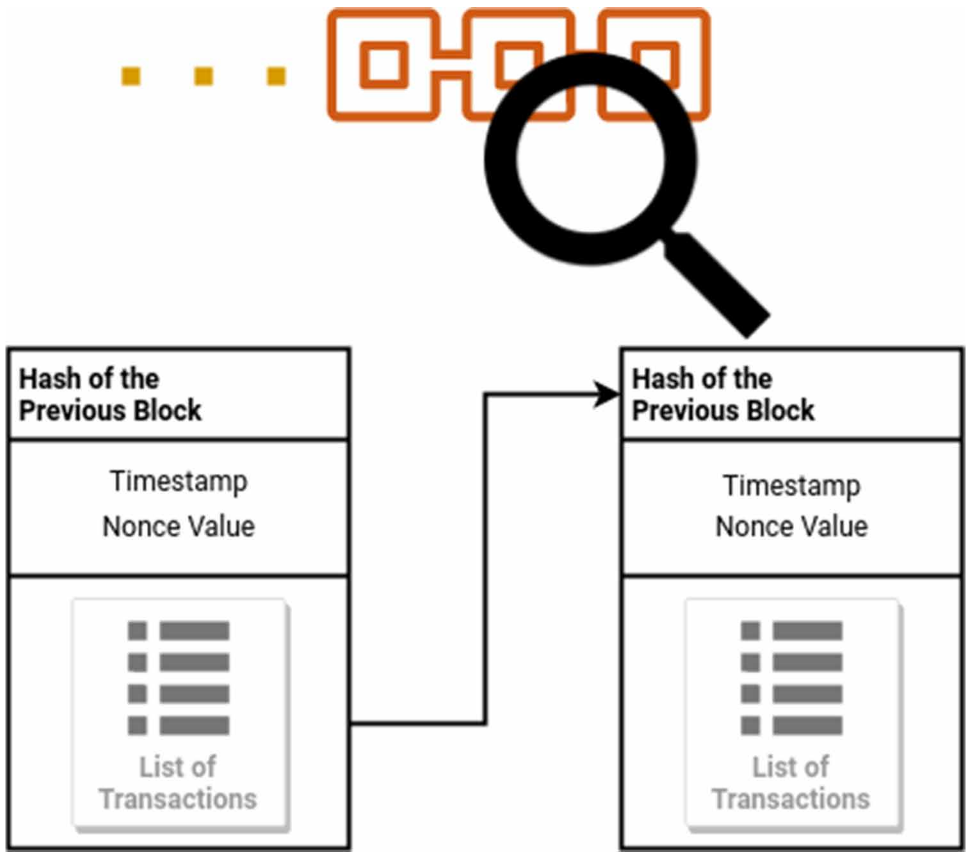
For public blockchains such as Bitcoin, Proof-of-Work (PoW) provides *consensus* for the transactions and enables anyone to enter the system without time constraints or approval from a centralized authority. PoW is the process of finding a nonce value such that the list of transactions in the block combined with the nonce value yields a hash value within requirements. Since computing the hash value is computationally expensive, participants in the blockchain (called miners) have to expend CPU power and electricity to participate.

Bitcoin is the first successful realization of a cryptocurrency, a decentralized value system that is not backed up with a physical good. Previous “e-cash” systems failed because they relied on trusted central intermediaries. On the other hand, bitcoin is inherently tamper-proof because attackers are incentivized to contribute their resources to the value of the currency of the chain. If a malicious actor instead decides to spend resources to attack the currency, they would have to bolster more computation power than 51% of the participants to the network and even if they are successful, the currency loses value because of their efforts, rendering the gains worthless.

Blockchain implementations have been proposed according to different access classifications. *Bitcoin* is a fully public, open and permissionless network where participants can join the chain at any time. *Private blockchains* require authentication and authorization before participation in the form of network access or encryption. *Consortium blockchain* networks are extended private blockchains. They house validator nodes that govern which participant nodes can present consensus for transactions (Puthal et al., 2018). They are often built by organizations with a common goal but potentially competing interests, which is similar to how supply chains operate. Thus, consortium blockchain networks are often the starting point for pilot studies mentioned in this chapter.

Blockchain has a reputation for costly transactions in terms of time and electricity required. This is often discussed at the forefront among the disadvantages of blockchain implementations (Puthal et al., 2018). Since Bitcoin is a public ledger with no access requirements, the costly PoW has to be in place against 51% of attacks. The blockchain implementations for the supply chain operations have been drafted up to use permissioned or consortium structures, where the costly PoW is not required (Yiannas, 2018).

Figure 2. Simplified structure of a blockchain.



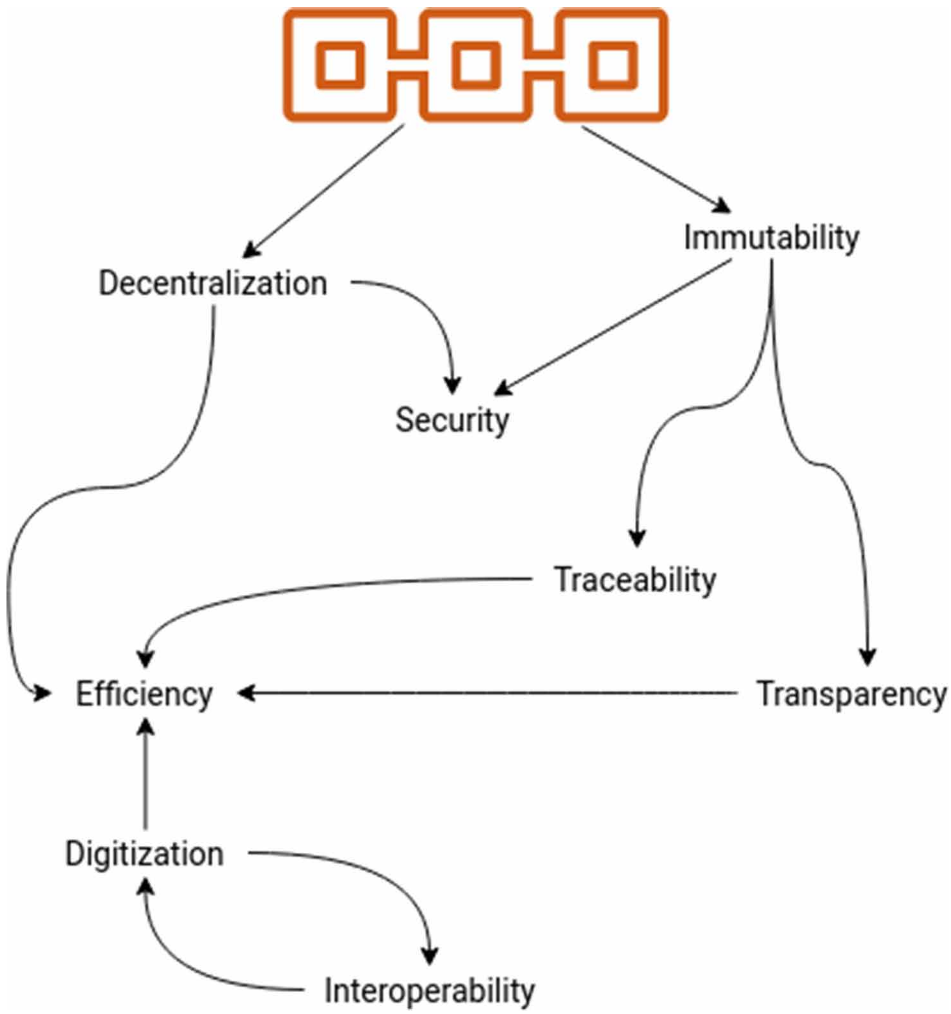
Smart contracts are used to extend the blockchain's capabilities further. They are programs that can be baked into the blockchain with their own addresses. They execute custom logic based on the blockchain state and transactions they receive (Christidis & Devetsikiotis, 2016). Since smart contracts are computer programs that run arbitrary scripts, they can be programmed to verify the quality standards of blockchain input using sensor data (Azzi et al., 2019).

Suitability of Blockchain for Supply Chain Management

In the literature, empirical studies on blockchain integration to the supply chain operations have been limited (Wamba & Queiroz, 2020). However, it is possible to derive the potential benefits of blockchain technology for supply chains from surveys done by research institutes, pilot studies by corporations, and framework proposals from the literature. In this section, the authors present certain suitable aspects of blockchain technology that could be or have been useful to manage supply chains.

In a survey conducted in 2018 regarding the potential uses of blockchain in operations of their companies, four out of five respondents said that their company will use blockchain primarily for the benefits towards traceability and transparency (Pai et al., 2018). These benefits include product tracking and provenance pinpointing.

Figure 3. Relation diagram of the suitable aspects of blockchain technology



Through the blockchain integration to supply chain literature, it is common to come across notions such as "the problems that blockchain solves can be solved using other tools". As Babich & Hilary (2020) puts it; *Very few things are not technologically feasible without distributed ledger technology. However, some of these possibilities are not economically feasible, and for many, distributed ledger technology is more economical.* Kshetri (2018) addresses the same sentiment by saying that blockchain solves a *messaging problem* more than *a database problem.*

The following are the beneficial attributes the blockchain technology can offer to supply chain management. The relationship diagram of the aspects is provided in Figure 3.

Traceability

This refers to the ease of tracking the source of a product along the supply chain. Extending this idea to multiple levels, traceability is achieved when a product's journey through a supply network is available and can be accessed in a quick manner. Differentiation between perishable products such as food or pharmaceuticals or electronic components is not necessary. It is intuitive to think that electronics are put together from many components procured from different manufacturers but an ingredient for an item sitting on a grocery shelf was probably distributed for use in thousands of products at one point in the supply network (Yiannas, 2018). The traceability process should not only be possible, but be quick as well. In the blockchain integration pilot study by Walmart, a packet of mangoes was traced to the source farm with the traditional paper-based record keeping system in about a week (Yiannas, 2018). During a crisis related to food contamination, a week's traceability period may not be acceptable.

Furthermore, traceability allows a company to isolate contaminated batches should any occur or avoid unnecessary blame while the products that are traced to safe origins do not need to be wasted. Traceability is a valuable target to optimize when a company wants to present their ethical means of sourcing or sustainable business practices. In a holistic view, organizations that raise their traceability standards increase ethical compliance, reduce the cases of missing products during shipments and fraudulent products for the whole supply network (Chang et al., 2019). In electronics manufacturing, traceability helps with authenticity (Xu et al., 2019). Blockchain helps traceability as follows; every product or document is created alongside its digital twin. Real life transactions where products or documents change hands between the participants of the supply chain also create a transaction on the blockchain where the digital twin is exchanged and committed irreversibly to the ledger, which is shared between every entity in the network. The final recipient of the real life good can trace the digital token from creation to destination (Francisco & Swanson, 2018). The link between the token and the physical good is preserved using serial numbers, bar codes, sensors or RFID chips (Schmidt & Wagner, 2019).

Transparency

Transparency is the ease of access to the information about a product. It is subtly different from traceability since transparency deals with what the product consists of not where the product comes from. An edible product with good transparency translates to readily accessible allergen information for people with health complications or a trusted ingredient list that people with dietary preferences can rely on. Organizations with halal, kosher or organic product profiles can benefit from increasing their transparency – by way of gaining consumers' trust (Chang et al., 2019). Transparency is an open problem for supply chains because of too many stakeholders along the chains. For instance, in 2018, over 3.5 billion dollars were lost due to failure to disclose allergen information in food items (Maberry, 2018). Implementing blockchain technologies enables meeting transparency requirements by tracing the ingredients of a product through the chronologically sorted list of transactions.

Immutability

This is the finality of each transaction committed to the blockchain. Altering a previous transaction on the blockchain calls for altering subsequent transactions while the rest of the network is moving forwards with the correct shared state. Overall, immutability provides the basis of the traceability and transparency by securing the trust to the blockchain's state. Additional security measures that protect an organization's data storage integrity is alleviated with blockchain integration.

Efficiency

Integration of blockchain technologies brings the ability to integrate smart contracts to the supply networks. With smart contracts and the verification power of IoT devices, rote procurement processes can be offloaded to frictionless automation including ordering, payment and invoicing. Decentralization and traceability is relevant here for the elimination of the bullwhip effect. As mentioned before, JiT operations have been getting traction to optimize inventory and production facility utilization. Real time tracking through IoT sensors can lead to ahead-of-time operations with the ability to track even the minute details and small batches (Kshetri, 2018). Finally, dispute resolution between buyers and the sellers get benefit from the efficiency aspect with the immutable history of the transactions ready to audit for either party (Chang et al., 2019).

Digitization

As organizations reach interoperability milestones, transaction data such as bills of lading, certificates and product information as well as the product's journey can be available as raw data. Data aggregation is useful for decision making and optimization processes especially combined with big data applications and machine learning. IoT data, product journey, sensor readings such as temperature and humidity and even video data should be readily available for this purpose (Liu & Li, 2020). Digitization of transaction documents or elimination of paper trails is tied to the efficiency of transactions. For instance, logistics company Maersk has found that their shipments would wait unnecessarily in ports due to missing paperwork which would have been tied to the digital twin of the shipment with blockchain integration (Kshetri, 2018).

Decentralization

Decentralization for the present study is related to eliminating single points of failure within the supply chain. Integration of blockchain ensures accountability and trust across the supply network by ensuring that each participant has access to the shared and trusted state. The democratic consensus process confirms this further. The transparency aspect of blockchain integration stems from decentralization as well; the ledger is distributed to all parties. Current supply chain transactions establish validation by assigning the arbitration of trust to a third party verifier, driving up the cost of a transaction (Zhang, 2019). After widespread blockchain adoption, these verifiers will be shifted towards the entry points of the supply chain to assure correct human or sensor input to the blockchain. The rest of the transactions along the supply chain are between blockchain participants, and verification of those transactions are handled through the consensus mechanisms (Babich & Hilary, 2020).

Security

Security follows from both immutability and decentralization. Immutability protects the record keeping system from loss of integrity while decentralization provides protection from attacks against accessibility (Min, 2019). Traditional database management systems need to have protection against these threats while ledgers run on blockchain technology are intrinsically secure. Additionally, through the choice of appropriate consensus algorithms and validator nodes, the blockchain can be secured in the presence of untrusted nodes (Toyoda et al., 2017). It should be noted that untrusted does not necessarily equate to malicious. Competing participants with potentially diverging interests (Babich & Hilary, 2020) also calls for security measures. Finally, blockchain integration is used for secure document exchange and storage with cryptographic security and is used for "identity validation for assets and individuals" (Kshetri, 2018).

Interoperability

As mentioned before, current supply chain information exchange is majorly done manually, with pen-and-paper methods, but organizations keep their records on traditional database management systems. These systems are tailored to the organizations and are effectively walled gardens in terms of data access from third parties. Interoperability in this context refers to systems readily accepting each other's communications and data. Standardized blockchain transactions or API requirements are part of interoperability as well. Interoperability is not necessarily a direct benefit of blockchain integration but an important milestone when gradual adoption of blockchain integration of organizations happens. Blockchain integration after reaching the interoperability milestones allows for the digitization of the supply chain and the opportunity to use Internet of things (IoT) devices and sensors for enhancing the quality requirements tracking. The temperature, pressure or other variables of the products shipment can be tracked in real time and through smart contracts, committed to the blockchain automatically. GPS trackers and the chronological ordering of blocks allows for real time tracking and pinpointing of goods during transit (Kshetri, 2018).

Use of Smart Contracts and IoT

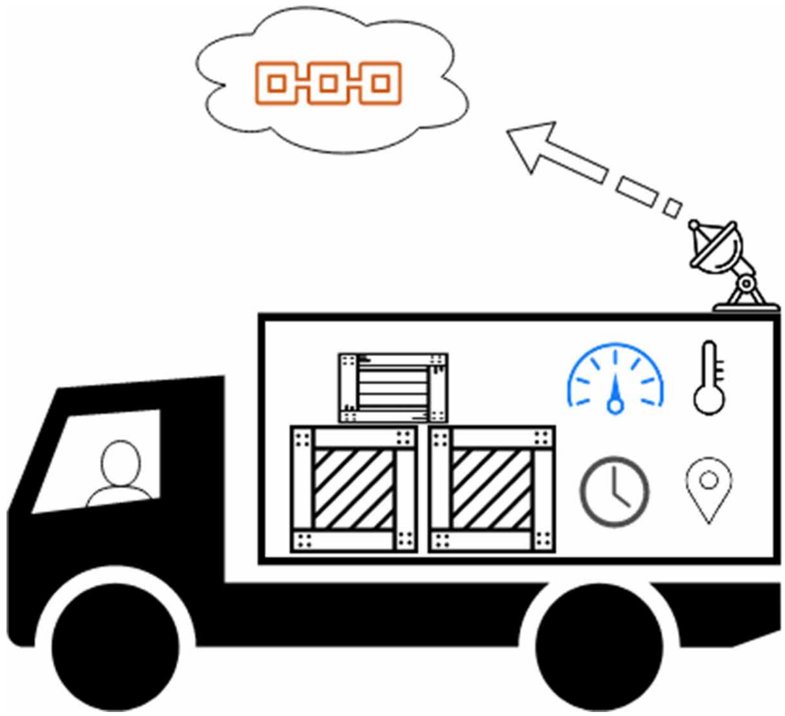
In the context of blockchain technology, tokenization is the process of creating a digital twin for a physical or intangible asset, by constructing a representation for it, to be input to the blockchain (Schmidt & Wagner, 2019); (Cameron-Huff, 2017). The resulting token is a record of proof for the whole or parts of the digitized asset. The owner of a block therefore owns the whole physical good (i.e. an amount of gold bars), parts of the physical good (i.e. some share in a real estate) or, if the asset is intangible, record of emission allowance or top-level domain names.

Inputting data to the blockchain involves tokenizing the physical goods or digital assets. Once tokenized, blockchain handles the security, mainly integrity, of the ownership of the assets in a cryptographically verifiable way with clear timestamps (Christidis & Devetsikiotis, 2016), even against the presence of malicious nodes, even in permissioned networks (Azzi et al., 2019).

With the leeway offered by the tokenization and secure transmission of data with blockchain, literature has suggested ways to harness the previously mentioned smart contracts for increasing efficiency in supply chain operations. Figure 4 illustrates a shipment of cargo using IoT sensors and blockchain integration.

Liu & Li (2020) have proposed a blockchain framework with a multi-chain structure where the sensitive account data is separated from transaction data and the data generated by IoT devices. This framework addresses the separate access frequencies and data requirements of three types of data while offering the ability to define access restrictions for each of them. El Maouchi & Ersoy (2018) suggested and empirically analyzed a generic supply chain traceability framework powered by blockchain. Their framework is proposed for a public blockchain structure and assumes secure input from the environment.

Figure 4. Real time product tracking using blockchain and IoT sensors.



Reyna et al. (2018) conducted a literature survey on blockchain and IoT integration. The authors suggest that blockchain integration can help IoT communications by providing data reliability. Furthermore, blockchain can provide unique identifiers for each device on the network and a trusted authentication scheme. They have identified three communication architectures for use in blockchain integration. The first one is *IoT-IoT* where IoT devices communicate directly with each other for low latency applications while blockchain only provides the addressing and authentication framework. The second architecture is *IoT-Blockchain,* where IoT devices have to use blockchain as a database to query and act autonomously. The transactions are immutably committed to the blockchain for this architecture. The third architecture is the *Hybrid approach* in which the previous two architectures are combined, where appropriate, to create a full operation definition. The authors claim that the hybrid approach is the best way to integrate IoT to blockchain applications since it leverages the real-time capabilities of IoT with the aforementioned benefits of the blockchain.

Bumblauskas et al. (2020) conducted a pilot study alongside a company regarding egg tracking in the United States. The company used temperature and humidity sensors to collect data about the transit of the eggs from the farm to the customers. During the proof-of-concept study, consumers could scan a QR code in the grocery stores with their smartphones to access the provenance of the carton of eggs they are holding. Behnke & Janssen (2020) have documented *boundary conditions* for a dairy supply chain to meet traceability requirements. Authors have conducted interviews with the organizations on dairy supply chains during 4 case studies. They found that the standardization of data and the selection of governance structure are the main driving factors of blockchain integration.

On the other hand, (Marsal-Llacuna, 2018) claims that a system with blockchain integration that relies on IoT data requires massive computing power and will not be feasible. However, the author only considered public blockchain structures where the limiting factor is the expensive PoW consensus algorithm.

ADOPTING BLOCKCHAIN TECHNOLOGY FOR SUPPLY CHAIN MANAGEMENT

While all of the suitable aspects of blockchain require an ensemble of organizations with a common goal and diverging interests to participate in the blockchain and provide consensus for the transactions, the interoperability aspect requires a much stronger action. While the blockchain is inherently decentralized, the standards for transactions, characteristics of the blockchain and the technical details like the choice of consensus method or the existence of validator nodes has to be agreed upon. Adoption of blockchain technology can propagate in two directions: top down integration is possible when a large retail corporation requires its suppliers to join the blockchain, or bottom up approach when suppliers at the start of the supply chain start participating in the blockchain and showcase the benefits to the distribution companies (Kshetri, 2018).

This section is dedicated to the details of the blockchain integration process, mainly the parameters of the blockchain and the initial data input issues.

Blockchain Modes of Operation

Blockchain networks operate under two basic access principles; permissioned and permissionless. According to Wüst & Gervais (2018), permissionless or decentralized mode of operation is the use case that could leverage the true potential of blockchain technology. Furthermore, if all of the parties of a network are fully trusted, then a private permissioned blockchain implementation is redundant and a traditional database system should be used instead. A supply chain is not a network where all parties are trusted due to the competition, they are in.

Environment to Blockchain Input

The integrity assurance of blockchain is at its weakest at the time of initial human or sensor input to the blockchain (Schmidt & Wagner, 2019). The threat actors here are rouge/malicious humans and malfunctioning or tampered sensors (Wüst & Gervais, 2018). Babich & Hilary (2020) call the potentially insecure input to the immutable blockchain transition the *state zero problem*.

The transactions on the blockchain are agreed upon by both the buyer and the seller during consensus. Babich & Hilary (2020) say that this is only a partial solution. However, Rodney & Zuckerman (2019) claim that use of IoT sensors fully solve the issue. This finding is supported by Queiroz et al. (2019) as well, who identified IoT devices to be especially useful for ensuring that the initial input from the environment to blockchain is legitimate. These sensors may include temperature and weight sensors, barcodes and RFID tags. For perishable materials such as pharmaceuticals and food items, gel-like trackers that do not disrupt the items can be used. Literature has also suggested successful PoW techniques that identify fraudulent food items without opening their containers (Ha, Leng et al., 2020). Value of these proposals are apparent when considering the statement by a wine authenticator "The value of fraudulent fine wine in circulation may be as much as $1 billion" (Adam Lechmere, 2016). The diversity of these methods underlines the interoperability requirements of blockchain implementations as well as the redundancy that could be established by using multiple sensors and sensing technologies.

Consensus

Another avenue for reaching consensus over the requirements and quality standards for assets in a transaction is relying on external *oracles.* Simply put, oracles are 3rd party entities that actors on the blockchain rely to verify the authenticity of transactions. The use of oracles inadvertently skews the decentralized nature of the blockchain platform by implementing trust on a central authority. The company ChainLink (Ellis et al., 2017) have suggested a decentralized oracle structure to solve this issue.

Depending on the access requirements of the blockchain network, a suitable consensus algorithm should be utilized. Permissionless or public networks use expensive PoW to reach consensus in an environment with no trust. Since blockchains for supply networks fall into the consortium blockchains category, expensive PoW is not preferred. Algorithms like Practical Byzantine Fault Tolerance that work under permissioned settings and provide resistance to ⅓ of the network acting malicious are suitable.

CASE STUDIES

The blockchain emerged as a linked series of transactions, thought as the driving power of a new currency. For the purposes of supply chains, the core idea of keeping an unchangeable chronology of all transactions within the system has carried over. Blockchain can be hard to untangle from its Bitcoin roots and the hype that still surrounds it. However, the seemingly simple idea of all transactions being agreed on and final can be built upon. In the end, thinking about blockchain as a shared data storage, that all writers and readers can trust. is the basis of all implementations.

Blockchain technology has caught the interest of organizations, especially the food industry and retail. The most commonly cited reasons for this interest are the outbreaks stemming from contaminated food.

Between April and May 2018, Capgemini Research Institute asked 731 organizations on various supply chains about the blockchain adoption progress in their organization. 447 organizations responded with an even split into manufacturing, retail and consumer products. Among the answers; only 3% are using blockchain in their daily operations, 10% are doing a pilot study with blockchain, while 87% use it as a proof of concept. The survey has also found that the most popular benefit of blockchain in supply chain operations for organizations is traceability and transparency. A more tangible benefit is the management of supplier contracts. (Pai et al., 2018).

Recently, Deloitte Insights have conducted a survey of 1,488 senior executives and practitioners from 14 countries, between February 6 to March 3, 2020, on the organizational stance on blockchain (Pawczuk et al., 2020). Since the research institute has been conducting similar surveys for the past 3 years, they have gathered some data for the adoption progress of blockchain over the years. For instance, the percentage of respondents that replied that blockchain is a top 5 priority for their organization climbed up from 43% to 53%. The authors of the survey report this finding as indicative that “blockchain is now an integral way of doing business”. Among the answers that saw a rise in positive answers e.g. “My organization or project will lose a competitive advantage if we don’t adopt blockchain technology and Our executive team believes there is a compelling business case for the use of blockchain technology within my organization or project" are further indications of this adoption. However, positive answers to "Blockchain is overhyped" has also risen.

Blockchain technology requires decentralization of work. A blockchain implementation planned to be used only within an organization is a waste of potential and resources. This type of closed implementations of blockchain as data storage should be left to traditional data storage solutions like databases (Wüst & Gervais, 2018). Furthermore, decentralization is possible only with proper onboarding procedures and adoption incentives so that different parties, even competitors, participate to the blockchain and be a part of the democratic consensus process.

In order to ease the inventory management, Walmart required its top 100 suppliers to adopt RFID tags by January 2005. This is an example of top-down propagation of adoption, discussed under the Adoption of Blockchain in Supply Chains section. A major retail-forced adoption of an innovation to smooth off the transition phase is the uphill phase of the network effect. Similarly, an organization with enough incentive can hasten the adoption of blockchain. On the other hand, according to the founder of the blockchain for automotive industry initiative MOBI, Chris Ballinger, *the network effects will be very strong* in the industries that use blockchain technology and *if you're not in at the very start, it may be too late* (Shiraz Ahmed, 2018).

Traceability is an integral requirement for supply chains that deal with food. It is well justified by retailers, manufacturers and consumers. Retailers would like to pinpoint the provenance of items in case of contamination or similar issues that would lead to a recall process for the product. Manufacturers would like to avoid misplaced blame when their product is not the cause of an outbreak so that they do not have to issue recalls or lose reputation tied to their brand in the face of the public. Finally, customers would like to purchase food items that are held up to standards (Tan et al., 2018). Pai et al. (2018) have reported that "a typical beverage recall would have cost 8 million dollars in 2017 and 456 food recalls in the United States is estimated to cost 3.5 billion dollars". For the majority of the recalls, the culprit is undeclared allergen information (Maberry, 2018). In other words, the food industry lost upwards of 3.5 billion dollars due to lack of transparency and traceability. It is no wonder that the initial surge of blockchain adoption in supply chains targeted the food industry.

Traceability has another value proposition for organizations that would like to gain the trust of the customers through concern for environmental causes and sustainability. An estimated €966 billion opportunity exists for brands that make their sustainability credentials clear (Unilever NV, 2017). Survey done on five countries and 20 thousand participants found that customers are conscious of the environmental impacts of their products and given choice, would prefer brands that are sourced and produced sustainably. This is especially true for customers in developing countries. For organizations that are integrating sustainability into their operations, blockchain is part of the solution for conveying this stance to customers. The tuna fish tracking pilot study done by Provenance gives further insight on how the initial sourcing process of the materials can be input to the blockchain and propagated up the supply chain all the way to the customers.

During the rest of this section, the authors present the real-life use cases of blockchain integration to supply chains in accordance to accounts by the organizations that conducted the studies.

Tuna Tracking by Provenance

Provenance is a London based blockchain startup. They have been conducting pilot studies for different supply chains with reports and documentations of their experiences. During these studies, the company worked with organizations and people from fashion, textile, cosmetics and coffee industries to name a few. The most extensive report, which is covered in this chapter, is given for the yellowfin and skipjack tuna fish tracking in Indonesia.

In a 6 month long pilot study in 2016, Provenance built a blockchain for the end-to-end traceability for tuna fish in Indonesia (Provenance, 2016). Traceability of tuna sourcing is especially important for the region due to unethical sourcing practices with the extreme examples reaching to the point of slavery. Provenance identified that the fishermen have access to mobile phones and set up their system to work with simple SMS messages as input. They used smart tagging to tokenize the fish in the form of NFC-enabled smart stickers.

The aim of the pilot study was to aid the industry of the region with the proof of compliance to standards. Fishermen are certified for their compliance to sustainable catching as well as protecting them against unethical labor practices. Another aim was to prevent "double-spending" of certificates. A holistic view for the study regarding the company is "exploring how these new technologies could form the basis for an open system for traceability powering consumer-facing transparency for food and other physical goods".

The pilot study has successfully demonstrated the possibility of integrating blockchain to an end-to-end supply chain, starting from the source all the way to the consumer. The data that flows through the supply chain and committed to the blockchain has been successfully ensured to be interoperable.

Food Tracking by Walmart

Improving supply chains that deal with food items has been the focus of recent research. Food items are especially susceptible to fraud and tampering due to the large amounts they get shipped in (McKenzie, 2018). While fraud and tampering, such as dilution or faking, is detrimental to consumer health, disastrous consequences stem from outbreaks that use contaminated foodstuff as disease vectors. One particular case of E. coli outbreak during 2006 is of interest since the offending batch of spinach that hospitalized 102 people and caused the death of 3 has found to have originated from a single lot (Centers for Disease Control and Prevention, 2006). There is an apparent value in the ability to identify the procurement of food items.

When the president for food safety of Walmart realized the difficulties surrounding the tracing and tracking food origins, they conducted a simple experiment (Yiannas, 2018). They purchased a packet of sliced mangoes and asked their team during a meeting to track down the farm that harvested the product that they are holding in their hand. The supply chain involving the mangoes used pen and paper methods for keeping a ledger of mangoes. This paper trail is not scalable and the information available in one party is not directly available in another. Furthermore, as discussed earlier on in this chapter, due to sheer complexity of supply chains, organizations are aware of only the neighboring portions of the supply chain. Eventually, it took 6 days, 18 hours and 26 minutes for the team to track down the farm that harvested the mangoes. Leaving non-essential goals such as informing customers about the ethical harvesting processes aside, that is potentially a week for an organization to gather data during a potential outbreak from contaminated food.

After the successful pilot study, Walmart invited other food retail companies and together they formed a coalition of ten Foundation Partners composed of both suppliers and retailers, which include Walmart, Kroger, Wegmans, Tyson, Driscolls, Nestle, Unilever, Danone, McCormick, and Dole. As the consortium, the pilot study continued and "as of May 2018, Walmart has already tracked nearly two dozen SKUs involving 2.6 million food packages across 166,000 traceability events on the blockchain in production environments”.

A decentralized system fails if it is not interoperable. The current consensus going forward from those who applied blockchain on the field are implementing open systems with simple onboarding processes and robust data input. Blockchain should be decentralized but the implementation should not be monopolized. No single food retailer can mandate better food traceability, food manufacturers in one country cannot do it alone, nor can any single country’s regulatory agencies. Better food traceability requires collaboration, and it must be people led and technology enabled.

When consumers visit a grocery store, they want to know whether the ingredients in their product have been sourced ethically. While it is not a constantly present concern, news of disregarded labor practices or sourcing through slave labor would upset consumers as well. Furthermore, customers prefer sustainable methods that are not harmful to the environment. Some consumers have strict dietary requirements such as vegetarians and vegans. Requirements of others go beyond the ingredients list and reach to the sourcing process; for instance, halal food requirements are concerned with the slaughtering process of the animals. Finally, allergen information should be covered under transparency.

High Value Items Tracking by Everledger

Everledger is a blockchain platform, founded for meeting the traceability and provenance demands of high-value items such as diamonds, wines, and luxury goods. The case of luxury goods draws a contrary case from the previous case studies since foodstuffs are relatively low-value items that require atomistic risk evaluation where the journey of a product from the farm to the plate of a customer can be planned in steps. High-value items that Everledger deal with require holistic solutions due to the increased threat to the high-value items (Kshetri, 2018). For instance, to overcome the state zero problems, Everledger’s operations include “scan and verify every diamond manually before its data is stored on the blockchain”, which the company has done for over 2 million diamonds, as reported in a 2019 study (Schmidt & Wagner, 2019).

Everledger has identified that customers have been raising ethical concerns regarding the provenance of the diamonds (George, 2020b). Their initiative to use blockchain technology was motivated by the immutability it provides (Price, 2015) which is the basis for transparency. The authentication process of high-value diamonds are tied to certifications and regulations; hence Everledger assigned Chow Tai Fook Jewellery Group to certify traceability, truthfulness, thoughtfulness and transparency; and independent diamond grading authority, Gemological Institute of America (GIA), to certify the physical attributes of each diamond as verifiers (George, 2020a). Similar to how Walmart presented its product’s traceability and transparency credentials, end customers can use their smartphones to access this information (George, 2020a).

CONCLUSION

Blockchain technology, with implementation details set aside, is a shared state with strong guarantees that the said state can be traced back to the very beginning, and is the same for every participant. Starting from this modest definition, it is possible to build some truly disruptive systems that can change how business, supply chains, energy grids, or communication systems operate.

Following the examples and case studies presented in this chapter, the next obstacle for blockchain integration to supply chains is the adoption phase. The network effect dictates that the adoption will be slow while the incentive to join the blockchain is low due to the lack of participants to the network. Presented surveys, that were conducted on industry professionals, indicate that the rapid adoption process might be getting closer.

The truly beneficial aspects of blockchain, namely digitization and efficiency which bring the ability to collect, learn from, and act upon data autonomously require interoperability. If the adoption phase of the blockchain leaves the industry with segmented networks that do not integrate with each other than each chain's value will get lower.

This chapter gave an overview of the aspects of blockchain that is beneficial for actors on the supply chain and presented some real-life use cases that gave valuable insight into the theoretical benefits of blockchain in real markets.

It should be noted that the future work of blockchain integration to the supply chain is vast. For instance, coordination of consortium blockchains, meeting the data processing requirements borne out of IoT devices, and securing the blockchain input against malicious actors or sensors are open questions.

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KEY TERMS AND DEFINITIONS

Blockchain: Blockchain refers to a decentralized history of transactions shared between various participant. The blocks of a blockchain are connected chronologically where each block is linked to the previous block. Changing an arbitrary transaction requires altering every block, while the rest of the network is following the longest chain.

Internet of Things (IoT): This refers to inter-connection of processing devices (computers, mobile phones, sensors, smart watches, and other smart devices) via the Internet to communicate, share and process data. Applications include Internet of Vehicles, Industrial IoT, smart cities, etc.

Interoperability: Interoperability is the degree of communication between two or more systems. When interoperability between systems is high, then they can communicate, share data, and use each other's functionalities. When the interoperability is low between systems then additional effort is required to translate one system's data types and communication protocols to the other, if possible.

Proof-of-Work (PoW): This is a computationally intensive task used in public open blockchain networks. It requires the participants to increment a nonce value to calculate a hash using the list of waiting transactions. The resulting hash value should be lower than a set limit. This busywork is in place mainly to select the transactions to commit to blockchain while protecting the network from malicious actors, as adversaries cannot bolster enough computational power to divert the blockchain.

Smart Contracts: Smart contracts are computer programs that can be assigned an address on a blockchain. Their code can execute and address transactions to other parties on the blockchain according to the state of the blockchain or according to the transactions they receive based on certain pre-defined terms. Smart contracts are useful to introduce automation to the blockchain.

State Zero Problem: Any input to the blockchain is irreversible so the tokenization process is delicate. If any mistakes occur or a malicious actor alters the information, the blockchain moves forwards with the erroneous information. If the tokenization process is secure, then the immutability characteristic of blockchain technology guarantees that the blockchain handles the rest of the security requirements.

Supply Chain: Supply chains refer to how a product's raw materials are sourced, constructed, assembled, distributed, and sold to a customer. These consist of multiple organizations that often span across countries.

Tokenization: This is the process of creating a representation of a physical item or asset to be used in the blockchain. This token is exchanged during transactions that match the journey of the asset, from sender to the receiver.