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INTEGRATING BLOCKCHAIN INTO SUPPLY CHAIN MANAGEMENT

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Abstract: *Since its inception in 2008, blockchain technology has found its place in many different areas. One of such areas is supply chain management, as blockchain technology and smart contracts can be used to verify the origin of the goods and materials, share information in the supply chain and automatize some of the transactions. In this paper, we will present some of the applications and potential issues with incorporating blockchain into supply chain management.*

Keywords: *Smart contract, Distributed ledger, Traceability, Information sharing, Applications*

1. INTRODUCTION

In the era of globalization, almost every item that we can find in our homes had to be transported through a complex series of organizations before it reached its final destination. From the sourcing of raw materials, through the manufacturing of the parts and assembling the final product, all the way to the transportation of the product to the end-user, many organizations from all across the world have to be involved, each adding a value to the final product. Because of this, it is often impossible for the end-user to trace the origin of the product and to find reliable information on where the product was manufactured, where the materials came from, whether it was produced in an environmentally sustainable way or whether the companies involved in the process of manufacturing used unethical labor practices. Moreover, even the organizations involved in the supply chain often can not find this information about their high-tier suppliers. On the other hand, it is evident that the end-users and companies would benefit from the increased transparency in the supply chain, as it would allow them to make an informed decision while purchasing the products or materials. Furthermore, the amount of direct communication and paperwork necessary to transport the goods between participants in the supply chain can negatively affect the productivity of the participants and slow down the entire process of delivering goods, thus lowering the overall profit.

For these reasons, companies and researchers around the world have put a lot of effort into optimizing the supply chain in such a way that it minimizes the negative effects of the aforementioned issues. During the last several years, blockchain technology has been proposed as a potential solution to these problems, as it would provide a higher level of security and fraud prevention. In this paper, we explored such applications of blockchain to supply chain management, focusing mostly on tracing the goods, providing relevant information about them, sharing information between members of the supply chain, and automatizing transactions.

The paper is organized as follows. In Section 2 we present the overall overview of blockchain technology and smart contracts. Section 3 contains some of the applications of the blockchain to supply chain management, and in Section 4 we present some of the issues with adopting this technology, together with some possible solutions.

2. BACKGROUND

2.1. Blockchain

Blockchain is relatively new technology that gained massive popularity by the appearance of Bitcoint cryptocurrency [14]. Soon, it became apparent that blockchain technology has potential for applications beyond cryptocurrency, and soon finds its uses in various areas such as healthcare [3], internet-of-things [10], digital rights management [17], supply chains [25], etc. Blockchain can be viewed as a distributed, decentralized append-only list of blocks, used in a peer-to-peer environment. blockchain being distributed means that everyone who uses blockchain has a local copy of its whole content. Arguably, the most important characteristic of the blockchain is that it is decentralized, meaning that it doesn't need any centralized trusted authority to manage it. Instead, the whole management of the blockchain system is done by the users themselves [16]. Being append-only means that once data is stored in blockchain, it can't be deleted or modified. Figure 1 illustrates part of a blockhain that consists of three consecutive blocks.

The users send data in form of transactions to the transaction pool. Special type of users, known as miners, select a number of transactions from the pool, verify them and group them in a block. Beside the transactions, the formed blocks contain data such as, block number, timestamp, the id of its creator, and cryptographic hash value of the previous block which is used to link all of the blocks in a type of linked list. However, because there is no centralized authority, the miner who forms a block must prove block's validity by executing consensus protocol [26] which is usually represented by a hard cryptographic puzzle, that a miner must solve. The solution of the puzzle is then embedded in the block, and the block is published. It must be noted that any user of the blockchain can decide to act as a miner. Once the block is published, the other users decide to accept it after they verify that the puzzle was solved correctly. However, it can happen that there are multiple valid blocks that are published simultaneously and in that case, every user may decide to accept any block that he wants. This can lead to creation of a fork in the list of blocks, which is usually resolved by users accepting the longest branch of the fork after certain period of time.

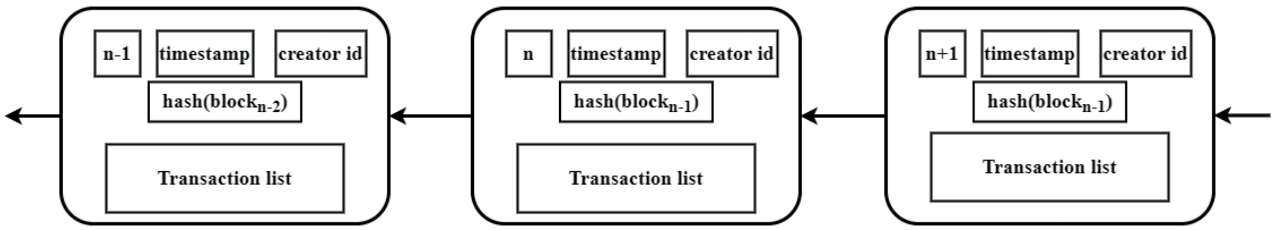

Figure 1 Illustration showing an example of showing three consecutive blocks of a blockchain.

2.2. Smart contracts

The term "smart contract" was first created and used in the mid 1990s, by a computer scientist Szabo, who defined them as a group of promises in digital form, that also include defined protocols that enable parties to fulfil those promises [19]. However, only when the blockchain technology appeared smart contracts lived up to its full potential. The blockchain platform Ethereum [1] introduced support for customizable smart contracts, by implementing Turing-complete virtual machine, known as *Ethereum virtual Machine* (**EVM**). Smart contracts represent a computer program that is executed on EVM, where every user of the Ethereum has an EVM implementation and executes the same code of the contract. Smart contracts are usually written using some high level programming language, most commonly the Solidity language. The code is then compiled into bytecode that is executed on EVM.

Smart contracts are submitted via transactions to the blockchain network, where they are verified by the miners and stored. [24]. The one who published the contract receives its address in the blockchain that can later be used to call methods that smart contracts implement. It should be noted, however, that because on the everyone must run the code of the called method, the execution can be rather costly. Blockchain mitigate this by having users pay a fee that is proportional to the number of instructions that are found in the method that was called.

3. APPLICATION OF BLOCKCHAIN TO SUPPLY CHAIN MANAGEMENT

A supply chain is a series of actions undertaken to deliver the goods from the initial supplier to the end customer through a series of organizations. It starts with the sourcing of materials and ends with the delivery of finished products. Along the way, each organization adds some value to the product. This process includes actions such as change of ownership, payments, transport of goods, security concerns, sharing documents and signing contracts between parties, customs clearances, and many others. Some of these actions can be automatized by using smart contracts and blockchain technology.

3.1. Traceability and verifiability

The most common application of blockchain to supply chain management is verifying the origin of a product and the way it was transported from its origin to the end customer. Currently, a customer usually has no way of verifying the source of materials used in a product, how a product was transported, or whether the production is sustainable from the ecological point of view. Not knowing this information prevents the end customer from making an informed decision. Additionally, providing the customers with this information can potentially be a huge competitive advantage for any company, as transparency can increase the trust between the company and its customers.

One way of overcoming this problem and increasing transparency is the use of blockchain technology and *radio frequency identification technology* (**RFID**). RFID is a wireless system composed of tags and readers. Tags are small devices consisting of integrated circuit and an antena, which can store a certain amount of data. Readers can read or write data from/to tags by using radio waves.

During the product's life cycle, it will be in a position of different organizations, including suppliers, manufacturers, distributors, retailers, etc. Each of these organizations can log some important information about the product into the blockchain, using RFID as a unique identifier of the product. For example, an organization can store ownership data, time stamps, location data, product-specific data, data about a person responsible for handling the product, or environmental impact data on the blockchain [2]. Since the data is stored in blockchain, it can be verified in real-time. Another advantage is increased security, as the data can not be changed once it became a part of a block. Furthermore, in the case of a faulty product, it would be easy to determine the cause and time of the problem and to take the appropriate measures, simply by inspecting the data stored in blockchain.

This concept can be taken one step further by integrating blockchain with the *Internet of Things* (**IoT**) in order to enhance the quality control of products. For example, transporting perishable goods can have certain constraints on temperature, humidity, or exposure to light. By including sensors that can detect unfavorable conditions, we can prevent damaged products from being used in further production, by automatically adding the data about the damage into the blockchain. As manufacturers rarely have the data on how the product was handled by higher-tier suppliers, this can prevent the company from unknowingly buying an inferior product and potentially harm its reputation. Examples of blockchain being integrated into agricultural supply chains can be found in [7, 12, 13, 20, 21].

Additionally, being able to trace the origin of the product and materials may prevent product counterfeiting, as each customer can verify the manufacturer and the path the product took before it reached the customer. This is especially important in the pharmaceuticals industry, as counterfeit drugs can have a negative impact on the users health [5], and it is estimated that around 50% of the medications sold online are counterfeit [4]. In a paper by Tseng et al. [22], the authors proposed a blockchain-based method for the distribution of pharmaceutical drugs.

In Figure 2 we present an illustration of a simple supply chain that uses blockchain with RFID technology for tracing products. Each participant of the supply chain interacts with blockchain by verifying the origin of delivered goods and writing new information considering the product, using RFID as a unique identifier. A customer can access all the data about the product on the blockchain. Government agencies and financial institutions can also monitor the data written on the blockchain.

3.2. Information sharing

The modern supply chains are highly complex systems that require a lot of communication and paperwork. Because of this, these systems are prone to errors and delays, and potentially use more resources than necessary. For example, a shipment from East Africa to Europe can require over 200 interactions and involve over 30 individuals or organizations, and by removing some unnecessary interactions the global trade volume could increase up to 15% [23]. By using the blockchain and smart contracts to track shipments and share the information with all the parties involved in the supply chain, it is possible to avoid most of these unnecessary communications and paperwork. This approach has already been adopted by Maersk and IBM, who provide a platform for tracking cargo based on blockchain and IoT. All the information about the shipment, necessary documentation, and activities are stored in the blockchain, allowing all participants in the supply chain to effortlessly access all the data, eliminating the need for direct communication. As a result, there are fewer mistakes, no unnecessary delays, and the system is more resistant to fraud. Furthermore, as the information about shipment can be accessed in real time, better optimization of storage facilities might be possible.

Another advantage of information sharing comes in a form of improved demand forecasting. Demand forecasting is a process of estimating the future demand for products based on past and current demand. In the traditional supply chain, forecasting demand can be a challenging process, as much information can be inaccessible to a particular company. Therefore, a company can create a forecast only for itself, potentially

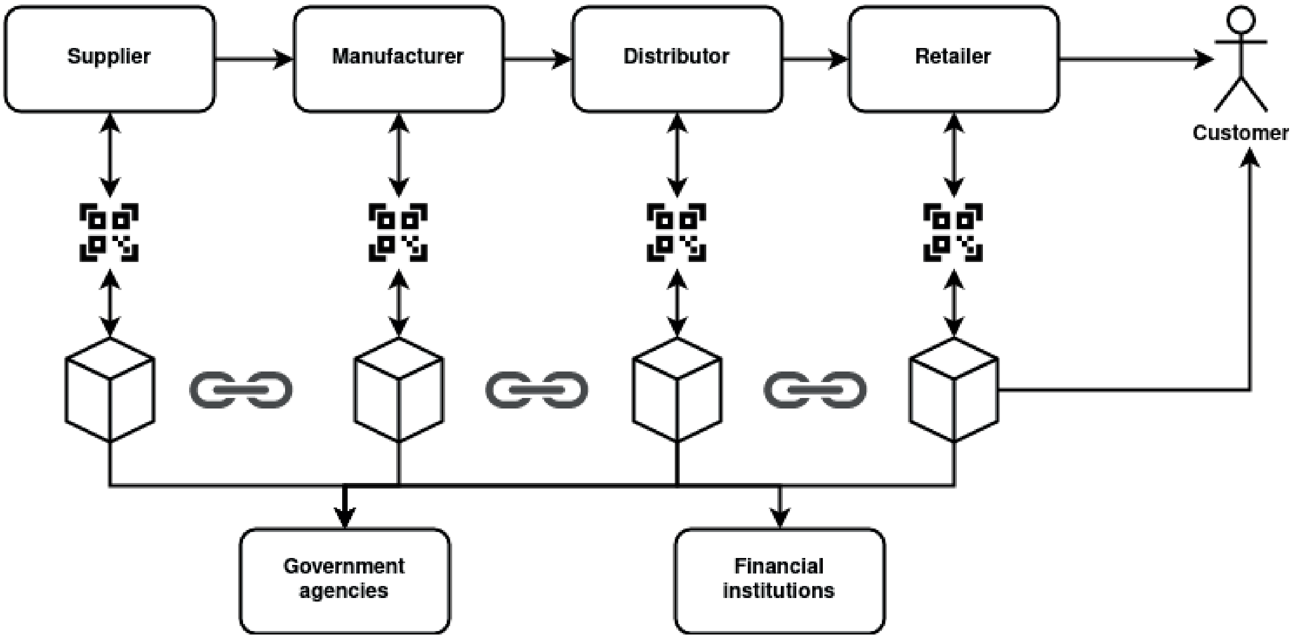

Figure 2 Illustration of a simple supply chain that uses blockchain for tracing products

leading to overstocking its inventory as a safety measure. In contrast, if the information about demand is shared among all of the participants in a supply chain, collaborative demand management becomes much easier, as it allows the participants to create one shared demand forecast, based on all available data.

3.3. Payment Automation

Payment automation in a supply chain can speed up the entire process of delivery and eliminate the need for unnecessary paperwork. By creating a smart contract, participants in a supply chain can order materials or services, by specifying the conditions under which the contract is fulfilled. The contract can not be changed unless all of the involved parties agree on making a new contract. Once the conditions defined in a contract are met, the payment is automatically released, eliminating the need for a third-party service, like a financial institution. This approach has already been presented in [8, 9, 15].

Another advantage of using smart contracts for automating payments is to overcome the lack of trust between two participants in the supply chain. For example, in the construction industry, it is not uncommon for participants to delay payments, or even forfeit them entirely [18]. As smart contracts are self-executing, the payment-related issues can be avoided, because the payment is released as soon as the conditions specified in the contract are met.

4. Potential issues

4.1. Security

In the traditional blockchain, each node can propose a transaction which would then be used to create a new block. In a supply chain, this approach can potentially create some security issues, as not all nodes have to be trustworthy. To remedy this issue, Gao et al. [6] proposed separating nodes into several types, based on their role in the supply chain. *Ordinary users* are the direct participants in the supply chain who can submit new requests for material, track shipments, and analyze the data. *Third-party users*, usually government and insurance agencies, monitor the data in the blockchain. *Supporting entities* interact with blockchain to provide particular services, like payment processing. Only these three types of users are allowed to submit new records to the blockchain. Additionally, there is the fourth type of user called *helpers* who maintain the blockchain by performing Proof-of-work to create new blocks. Like in the traditional blockchain, there is no limitation on who can be a helper, anyone interested can contribute to the creation of a new block.

Another security issue is the unauthorized access to sensitive information. Even though the transparency and easy access to data in the supply chain is generally desirable, some data stored in the blockchain might contain sensitive information that shouldn't be accessed by companies' competition or other unfriendly parties. This information can be encrypted, preventing unauthorized users and helpers from reading it. On the other hand, the user that created the encrypted data can make a list of authorized users who have a legitimate reason to read the data and grant them an access in cooperation with the *identity management component* [6].

4.2. Storage

The number of individual products that are being shipped daily is so high that it is virtually impossible to estimate. Considering that most of the products have to go through several organizations until they reach their final destination, the amount of data needed for tracking all of the products can be incredibly high. For example, tracking only one million products through ten organizations, where each organization adds only 200 bytes of information for each product to the blockchain, would result in 1.86GB of used storage space. Taking into account that the actual number of products is vastly higher, that products can travel through many more organizations, and that the amount of data written for each product can be considerably higher, it is easy to see that the storage of all the data can be problematic.

As a solution to this problem, Kumar and Tripathi [11] proposed using the *Interplanetary File System* (**IPFS**) as blockchain storage. IPFS is a decentralized, peer-to-peer network for storing and sharing data. After a miner chooses certain transactions for creating the next block, those transactions are stored in IPFS, and the miner receives a 46 bytes long hash value, that can be written into a block. Because the same data in the IPFS results in the same hash value, potential frauds on the blockchain can be easily detected.

5. CONCLUSION

In this paper, we presented some of the possibilities of applying blockchain technology to supply chain management. As the supply chains grow exceedingly complex, there is a need for reducing the amount of direct communication and for more transparency in a process of delivering goods. Potentially, blockchain technology could help with both of these problems, by allowing the involved parties to create smart contracts or to track materials and products in a more secure and fraud resistant way.

We presented several ways that blockchain technology could be incorporated into supply chain management in order to mend some of the existing problems. Furthermore, we presented some of the issues with the adoption of this technology, together with the possible solutions.

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