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Blockchains in operations and supply chains: a model and reference implementation

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Abstract

Blockchain is a promising information technology which can provide several potential applications related to operations and supply chains. By using distributed software architecture and advanced computing, blockchain can solve the problem of immutable ledgers distributed to several actors in the chain. This paper reviews blockchain technology and outlines possible uses for immutable distributed ledgers in operations and supply chains. A classification of the applications of blockchain technology in the scope of operations and supply chain management is presented. In order to demonstrate the technical architecture of the blockchain-based logistics monitoring system (BLMS), a reference implementation was programmed and tested based on Ethereum. The purpose of the BLMS is to provide a solution for parcel tracking in a supply chain to support an open and immutable history record for each transaction. The functionality of the system consists of transaction entry for logistics operators. The presented reference architecture demonstrates how blockchain can be implemented in the operations and supply chain context by using software components.

Keywords: blockchain, distributed ledger, operations, supply chain, logistics.

1. Introduction

Recently, the possibilities of applying blockchain technology have gained increasing attention in many industries. Blockchain is taking roles from important regulatory actors, such as notary services, central banks and other centralized trusted identity middlemen (Wright & Filippi, 2016). Blockchain can provide an immutable ledgers solution for several distributed participants in the chain by distributed software architecture and advanced computing technologies.

The critical features of blockchain are that it is distributed, verified, and immutable (Hackius & Petersen, 2017). Distributed architecture means that the system is not depending on any centralized authority but using a peer-to-peer network of computer servers maintained by decentralized interest owners. Every owner keeps a copy of the whole blockchain. However, blockchain can maintain security as each transaction is verified by using public-private-key cryptography, and the transaction records on the blocks cannot be modified once they are accepted as parts of the table chain because they are attached to each other. Any tampering with a transaction record would be notified by several computers in the network; therefore immutability of data content is effected (Önder & Treiblmaier, 2018).

Currently, blockchain is mainly applied in digital currency and the digital economy (Efanov & Roschin, 2018). Historically, bitcoin was the first application of blockchain, and subsequently several applications beyond bitcoin have been outlined (Underwood, 2016). Blockchain has the potential to provide disruptive applications related to different non-finance fields, such as the agri-foods industry (Tian, 2016), pharmaceutical manufacturers (Apte & Petrovsky, 2016; Bocek et al., 2017), healthcare (Esposito et al., 2018) and education (Chen et al., 2018).

Blockchain technologies can contribute to the operations and supply chain domain as well (Francisco & Swanson, 2018). Currently, supply chains are becoming more and more complex in structure, difficult in terms of task, and diverse in terms of stakeholders, and many organizations do not have an integrated view of the entire supply chain. Many large organizations have built their own identities and systems to maintain a global coverage of operations and have power to instruct their suppliers. Otherwise, they have to rely on centralized regulatory bodies or intermediaries. This low transparency causes many problems and difficulties in the supply chain mechanism in terms of security, traceability, authentication, and verification system. It is interesting to note that blockchain is well suited to address the challenges of supply chains, and therefore it is vital to adopt blockchain technology, with its features of immutability, transparency, and trustworthiness (Chen et al., 2018), to provide more visibility and security in the supply chain.

A blockchain-based supply chain is promising and trustworthy in traceability and authentication, even eliminating middleman auditors. As proposed by Kshetri (2018), one of the first possible functionalities is to apply blockchain to track all actions in the supply chain, such as who is performing the actions, at what time, and where the location of each action is (Kshetri, 2018). Every partner in the supply chain can track products, shipments, deliveries and progress. They can also easily measure the performance of each activity in the supply chain and monitor the quality of products during transportation (Chen et al., 2017). Therefore, a blockchain-based supply chain reduces the workload and ensures traceability, while increasing efficiency, reducing cost, and securing more confidence that the products are genuine and of high quality (Kshetri, 2018). Of course, the applications and usability of blockchain in supply chains are increasing consistently with the support of the Internet of things (IoTs) and machines providing operational data automatically. It is more efficient to track and control the objects from their origins by using IoTs (Francisco & Swanson, 2018). However, blockchain is still an immature technology in many aspects, and it is not transforming critical supply chain activities. Therefore, there is a wide gap between blockchain potential and supply chain realization. Additionally, many companies still have little knowledge about blockchain, and there are still not many ready-to-use applications of blockchain in the supply chain domain (Peterson et al., 2017). Many companies and researchers are trying to engage with the trend of blockchain deployment based on their business objectives, but the effects of blockchain on the supply chain have not yet been systematically assessed. Several open questions about blockchain remain in the research field. For researchers, it is interesting to investigate the direction of blockchain in the innovation of both business and technologies. For companies, it is interesting to know when blockchain will yield positive returns by overcoming the restrictions, and who will benefit most from it, particularly in supply chain management.

It is time now to solve these research problems and the research has great potential to create both academic and economic value in the supply chain management field. In light of the above observations, the purpose of this research is to illustrate blockchain's impact in the supply chain. To achieve this, possible uses and application of blockchain in the supply chain are outlined to help companies consider how to meet their business objectives. Moreover, a blockchain-based logistics monitoring system is implemented to analyze the feasibility of using blockchain in the supply chain. Therefore, this article aims to analyze these important gaps in the existing literature on blockchain deployment in the supply chain. In approaching the subject, the following research questions will be answered: '*What are the possible applications of blockchain in the supply chain?*' and '*How should blockchain technology improve activities in supply chain operations?*'

The paper is structured as follows. Firstly, a literature review is conducted by exploring the latest research on the key technologies of blockchain, applications of blockchain across industries, and the roles of blockchain in the supply chain in Section 2. Secondly, potential application functionalities are described followed by a reference implementation of an Ethereum-based application, in Section 3: this consists of a description of technical details and evaluations. Finally, conclusions about the technology are drawn in Section 4.

2. Literature Review

2.1. The Significance of Blockchain for the Supply Chain

Supply chain management (SCM) is an integrative concept to manage the total flows of a distribution channel (Helo & Szekely, 2005). The supply chain is complex because it includes distributed activities from upstream, which deals with people, physical resources and production processes, to downstream, which covers the whole selling process, i.e. contracts, sales to customers, distribution and disposal (Tian, 2016). The purpose of the supply chain is to establish a multi-stakeholder collaboration environment through mutual trust, to remove communication barriers, and make sure different companies are connected to pursue integration of the entire supply network on a routine basis (Tuominen et al., 2009; Korpela et al., 2017). Ultimately, related stakeholders in the supply chain can improve overall efficiency, and bring greater value and benefits to their business.

However, there are several critical issues in the current business operation of supply chain management. First of all, supply chain management is affected by the increasing applications of the Internet of Things (IoTs). With IoTs, the locations of products, packages and shipping containers can be tracked at each step to achieve information transparency along the supply chain (Francisco & Swanson, 2018). These tools and applications need centralized planning and coordination by a government department, a core enterprise, or a third party organization. However, in reality, these kinds of centralized organizations always have limited control, and lack the capability to manage the entire supply chain because they are opaque (Korpela et al., 2017). Users are also not able to know the inner details of transactions. On the other hand, many logistics-related identities are built either by large organizations to fulfil their own needs in the networks or they rely on centralized regulatory bodies, i.e. global 3PL (third-party logistics) companies. They have a global coverage of operations and have power to instruct their suppliers. This huge number of participants often causes the problem of low transparency.

Secondly, due to the globalization business, distributed production, and multiple information locations, information asymmetry and isolation are common issues in a large supply chain. It always has a low level of transparency and lacks an effective trust mechanism among different stakeholders in the supply chain. Most stakeholders have difficulty in obtaining an overall picture of all transactions and tracking the origins of products, especially customers and suppliers who can only partially access information across the whole supply chain. This causes the emergence of counterfeit products and product quality scandals which have a negative influence on the entire supply chain (Abeyratne & Monfared, 2016; Tian, 2016). This in turn could lead to problems of information fraud and extortion for supply chain members (Tian, 2016).

In order to establish trust and to realize a high level of transparency across the supply chain, it is important to optimize various information flows, create a holistic view of all relevant activities, and to integrate the whole supply chain by adopting advanced technologies, such as cloud-based solutions, and adistributed ledger system (Hofmann & Rüsch, 2017; Francisco & Swanson, 2018). Organizations can increase their overall performance, minimize the process risk, and achieve their business objectives. Applying new technologies will not only improve the functionalities of the business process, but also improve regulatory control through alleviation of stress of the core enterprise (Omran et al., 2016).

A well-known example of a collaborative approach for standardized processes comes from the retail logistics side. GS1 is an international organization maintaining logistics and transportation-related centralized identity repositories. The identities include EPC code (Electronic Product Code) base for retail products, SSCC code (serial shipping container code) for shipping containers, and GS1 company codes for identification of the member companies. According to its press release, GS1 has collaborated with IBM and Microsoft to leverage this standard in their enterprise blockchain application for supply chain clients. This blockchain application enables users to maintain and access a single, shared version of their supply chain and logistics events. This approach increases data integrity and trust between parties, and reduces data duplication and reconciliation (Sforzolini & Sullivan, 2017).

Blockchain is a sequentially and chronologically created open and distributed online database ledger, recorded and verified by a network of computer servers. These blocks are distributed among multiple nodes of an infrastructure, and are not centrally stored. Each block contains the information about all transactions in the system within a period of time. For example, the information includes a timestamp of its creation, the hash of the previous block, and the transaction details (Tian, 2016; Esposito et al., 2018).

This technology was introduced to larger audiences by Nakamoto (2008) in the context of bitcoin, a distributed managed digital currency. Several enhancements have been developed since the first bitcoin, and today there are many competing cryptocurrencies which are based on the same technological core of blockchains (Luther, 2016).

Blockchain combined with peer to peer communication network creates a system that solves two well-known problems in other digital currencies: the Byzantine consensus problem and double spending problem (Zohar, 2015). The Byzantine consensus problem is a mathematical problem where geographically separated generals on the battlefield cannot trust each other and also traitors can take place to convey counterfeit messages, but generals need to have sort of coordinated communication mechanism to attack simultaneously to the city in order to win (Lamport et al., 1982; Swan, 2015 pp.2). The double spending problem means conflicting transactions in the network: because is possible to replicate the payment due to propagation delays in the peer-to-peer network (Zohar, 2015; Crosby et al., 2016).

Blockchain can address challenges in the supply chain and also contribute to various vital objectives of supply chain management, such as cost, quality, speed, dependability, risk reduction, sustainability and flexibility (Kshetri, 2018). Therefore, the supply chain deserves special attention among the many other activities that are likely to be transformed by blockchain. Table 1 sums up the five main reasons for and benefits of applying blockchain in supply chain management.

Table 1. Benefits of applying blockchain in supply chain management

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

1. Tamper-proof transaction records: a blockchain is a data structure that makes it possible to create a tamper-proof digital ledger of transactions and share them. Technically, a public-private key cryptography is used to sign transactions among the parties. A 'public key' is used for verifying the transaction publicly amongst entities on the network, while the recipient can verify the transaction with the corresponding 'private key' (Apte & Petrovsky, 2016; Crosby et al., 2016; Badzar, 2016). The transactions are then stored on a distributed immutable ledger (Kshetri, 2018). This technology principle can enable real-time traceability and authentication of the source of products in the upstream supply chain, and also help strengthen the confidence of downstream supply chain stakeholders in the products' security. In this way, blockchain produces trust among suppliers (Kshetri, 2018). Moreover, this decentralized system can be implemented at a low cost (Bocek et al., 2017).
2. Information sharing & synchronization: demand forecasting is becoming more difficult because of short product life cycles and long production lead-times. In this situation, supply chains face the risk of either excess capacity due to low demand realization or lack of product availability (Nakasumi, 2017). This is the famous 'bullwhip-effect'. It is essential to reduce the information asymmetry and improve information sharing across the entire supply chain to reduce the capacity risk (Nakasumi, 2017). However, traditional information sharing methods, such as using EDI network to integrate different kinds of code schemes, or implementing an integrated ERP (Enterprise Resources Planning) system to realize visibility, are expensive and unrealistic. Therefore, blockchain is designed based on another core technology: the peer to peer network. Every node on a peer to peer network shares information and keeps a complete set of ledgers of past transactions in the model of both client and server. Therefore, each node reaches consensus on the current state of the distributed ledger and ensures information consistency (Chen et al., 2018; Peck, 2017; Efanov & Roschin, 2018).
3. Smart contract execution: smart contract is a computer protocol that simulates a real contract. It can control digital assets and formulate the participant's right and obligation. If a set of preconditions are met, the smart contract will be automatically executed by a computer system (Lin & Liao, 2017). It can facilitate contract negotiation, simplify contract terms, implement contract execution, and verify the contract fulfilment state. Therefore, relevant actions such as payments can be initiated in a transparent and efficient manner (Omran, 2016). In this way, it reduces 'third party costs', simplifies the supply chain management process, and also reduces risks (Chen et al., 2018).

2.2. Application Areas of Blockchain in Supply Chain Management

With the development of the Internet and availability of some other advanced technologies over the Internet, the supply chain has gone through a significant change in the last decade. Blockchain can be applied in four main areas: financial, healthcare, government and retail and manufacturing. As introduced in the previous section, blockchain is considered to offer tremendous potential for improving processes and enhancing business models in supply chain management. The features of blockchain allow several possibilities of use in the context of operations and supply chain management. The spectrum of possible applications is wide. In this particular research, the possible entities are summarized by assets, identity and ultimately transactions (Figure 1).

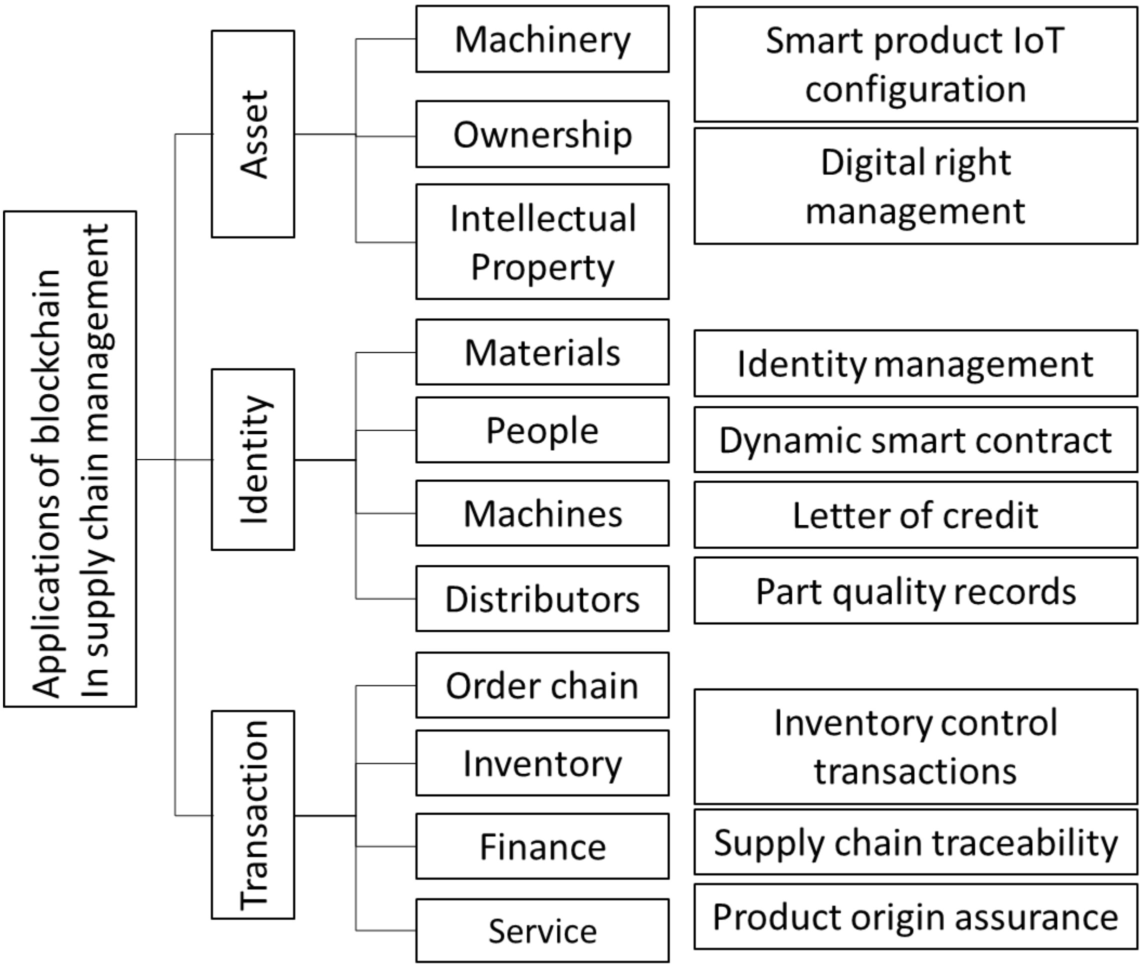


Figure 1. Examples of applications of blockchain in supply chain management.

- Assets: For both tangible assets (i.e. physical property) and intangible assets (i.e. documents), it is crucial to have accurate and reliable records to identify ownership and to ensure the correctness and completeness of property-related valuable information (Abeyratne & Monfared, 2016; Mizrahi, 2016). Further control of the physical assets may be achieved by registering and transacting the properties through blockchains as smart property or digital property management. It is possible to achieve traceability through the use of IoTs (Francisco & Swanson, 2018). This is a combination of blockchain and digital twins. Assets stored in the ledger are secured and accurate, as they are managed cryptographically by keys and signatures to determine who can transact within the shared ledger (Yeoh, 2017).
- Identity: The digital identity and private records can be stored and confirmed with blockchains through securely encoded legal documents. These non-financial applications include health records, licenses, ID cards, contracts, signatures, etc. (Crosby et al., 2016; Swan, 2015, pp.10). In the future, code-based smart contracts are computer programs that can execute most of the agreements, contractual relationships and governance (Yeoh, 2017). When a preconfigured condition in a smart contract among participating entities is met, then the parties involved in a contractual agreement can be automatically made payments based on the contract in a transparent manner (Crosby et al., 2016).
- Transaction: One of the key characteristics of blockchain is the decentralized and distributed transaction ledger. This results in a verifiable and permanent record of transactions between different

parties (Swan, 2015 p.10). All supply chain-related transactions can be registered and confirmed on the blockchain, including order, inventory and products.

2.2.1. Sustainable Supply Chains

Socially sustainable supply chains have been explored by Hutchins and Sutherland (2008). The authors studied measures of social sustainability and analyzed how these are applied in supply chain-related decisions. In general, socially sustainable supply chains require the known origin of raw materials and procedures which are in accordance with generally accepted practices.

The supply chain for diamonds or other rare earth metals is a good example of such a challenge. Diamonds are occasionally mined by groups funding war zone activities and sold to different locations to hide the origin of the raw materials. These so-called 'blood diamonds' and the use of child labor in mining (Epstein & Yuthas, 2011) are well-known sustainable supply chain problems. Many companies and manufacturers are very interested in ensuring that these kinds of raw materials are not used in their products (Nathan & Sarkar, 2011). Everledger is a company that has created a permanent ledger of diamond certification and transaction history through creating a digital identity for each diamond on a blockchain network (Crosby et al., 2016). This aids the authentication of the transaction, for example by preventing 'blood diamonds' entering the jewellery market. The verification of diamonds can be done by insurance companies, law enforcement agencies, owners and claimants. Everledger provides a simple-to-use web service API (application programming interface) for looking at a diamond, and creating, reading or updating claims by insurance companies, and the same for police reports on diamonds. Kimberly Process utilizes blockchains to build an unchangeable record for each diamond certificate (KP Chair, 2016). 81 countries are participating in the process, which provides a system of warranties of stone origins. Thus, these countries can trade diamonds inside the group, which can make up 99% of the total diamond trade volume globally.

More examples can be found in reality. Another example is the high-volume raw material category, namely timber. Sustainable forest policies should be followed, and the entire process from forest to paper should be recorded for tracing. Düdder and Ross (2017) have presented a blockchain solution for the problem of timber tracking. Moreover, vegetable oil has been sold as waste oil to become a recycled component in biofuels, and public funds have been used to fund such activities.

2.2.2. Safety Issues

Social sustainability is not the only reason for being interested in the source of the raw material and the practices conducted in the supply chain. Safety also plays an essential role in many industries. For instance, authentic food is another important part of sustainability.

Tracking and tracing are typical supply chain operation functions to achieve information transparency. These require a centralized and immutable database for transactions, users, locations and containers. A typical example of tracing in supply chains is the food industry. Endangered species have been used as raw materials in the food industry, but remembering the milk powder scandal in China, tampering with the food supply chain may cause large-scale dangers for people. Food fraud issues are also known in the horse meat case as well as with expensive wines. Generally, counterfeit food presents a public health threat. It is critical to have effective food supply chain management to solve the food safety issues.

For instance, in the case of a foodborne disease outbreak, retailers have to track down the source of contamination and other products which are also affected. Walmart partnered with IBM in 2016 to implement a blockchain-based system to facilitate origin and movement tracking for food items. In traditional existing IT systems, internal management of central databases and trust between the participants was required. With the new blockchain-based system combining with barcodes or auto ID technology, Walmart has achieved a substantial improvement in the transparency of both domestic and international supply chains. Data such as farm origin, batch numbers, factory and processing data, expiration dates, and shipping details were written on the blockchain and instantly became available to all network members. These data enable Walmart to track down the origin of food instantly if there is a foodborne disease outbreak (Shaffer, 2017).

Fake pharmaceutical products also present a threat. Digital technologies and serialization procedures in general have been presented to build identification systems for medicine (Mackey & Nayyar, 2017). Blockchain technology provides a solution for this, and has been tested in the pharma supply chain by Bocek et al. (2017). Blood supply chains are a specific type of product, where origin and transactions should be carefully linked to product history (Beliën & Forcé , 2012). In the medical sector, counterfeit drugs are a known problem that, for example in the case of anti-cancer drugs, can even have lethal consequences if patients do not receive the treatment as prescribed (Mackey & Nayyar, 2017). Blockchain can improve patient safety through establishing supply chain transparency from manufacturers through wholesale and pharmacies to the individual patients. Through barcodes or auto ID technology, patients can be empowered to check whether they have received the actual drugs (DeCovny 2017; Mackey & Nayyar, 2017).

Food tampering or the medical supply chain may cause large-scale dangers for people. Blockchain is considered to make it much more difficult to tamper with products or to channel in products of illegal origin (Sutherland et al. 2017; Apte & Petrovsky, 2016; Morabito, 2017). Therefore, blockchain-based solutions have been presented to fight anti-counterfeit products (Toyoda et al. 2017; Tian 2016; Spink & Moyer, 2011). Knowing the source and history of consumable parts is an important data element in the fight against counterfeit products (Staake et al., 2005).

2.2.3. IoTs based Smart Assets

Logistical objects are increasingly equipped with sensors that generate data along the supply chain. Taking Walmart and IBM as an example again, because of the benefits of IoTs and blockchain, more data attributes are scheduled to build up more blockchain-based solutions. Ultimately, Walmart believes that blockchain can also reduce food waste if the newly available data on shelf life is used as a parameter for supply chain optimization (Shaffer, 2017). In order to increase the transparency and effectiveness of the supply chain, this data has to be stored in an immutable and accessible way. Therefore, logistics might be one of the most promising applications for a combination of IoTs and blockchain (Zheng et al. 2017; Hackius & Petersen, 2017). IoTs sensors gather various data from the real world. Therefore, the locations of products, packages and shipping containers can be tracked at each step (Kshetri, 2018). Using digital representation to record a physical asset is the application of ‘digital twins’. The integration of digital twins and blockchain into logistics promises to enable the real-time tracking of material flows, improved transport handling, as well as accurate risk management.

Smart connected machines and installed base generally need to have systems to be identified and managed. IoTs provide an up- to-date connection from the device to the Internet. A Gartner report estimates there will be over 20 billion connected IoTs by 2020. Identification of asset and digital rights management for functionality are possible implications. Product configuration can be adjusted based on installed components and permissions allowed by licences. Blockchain is an element and a solution to connect and manage IoTs devices safely and reliably (Pilkington 2016; Christidis & Devetsikiotis 2016; Kshetri 2017; Zhang & Wen, 2017; Banerjee, Lee & Choo, 2017).

The advantages of IoTs and blockchain have been noticed by large companies. For example, Groupe Renault is prototyping a blockchain-based system to store the digital twins of its vehicles to provide a single source of truth for each vehicle's maintenance data. With this system, each vehicle's maintenance history remains connected to the vehicle even when there is a change of vehicle ownership. On the other hand, Bosch is also implementing digital twins of vehicles with a German certification authority to prevent illegal odometer manipulation.

In the aviation and automotive industries, pirated spare parts are a business problem and cause serious safety issues for several original equipment manufacturers (OEM). By using blockchain, all aspects related to the asset can be securely recorded. Pirate or cannibalized used parts of a machine can be identified when being installed into a new configuration. When a combination of several components is determined, each component can cross-check the validity of the parts and the entity formed from the components.

2.2.4. IPR in Digital Manufacturing

Besides tangible assets, blockchain can be also used to improve the security of protecting intangible assets, i.e. intellectual properties. Nowadays, conflicts and disputes over intellectual property rights (IPR) happen because some people have properties but cannot prove ownership. Some applications of blockchain are used to check the records of properties in the database to prove ownership. Other examples are critical business information, such as design drawings, corporate planning, and so on. This information may be stolen by industrial spies. Blockchain technology can be used to protect this valuables business information by recording data in a blockchain network (Chen et al., 2018).

Managing intellectual property related to production is becoming increasingly important when smart manufacturing systems can process parts from digitalized instructions. Computer-aided manufacturing (CAM) systems translate geometrical information about the parts into material, tooling and manufacturing code, which is executable by modern machinery. In the context of digital manufacturing, a method is needed to control the number of product instances produced by a legal licence. In practice, this means authorized serial numbered products, which can be verified for authentic origin. The emergence of 3D printing and the ease of translating 3D geometry for smart machinery have also encouraged traditional manufacturers to handle manufacturing IPR. For example, Piratebay launched the category 'Physibles' for 3D printable objects already in 2013.

3. Blockchain-based Logistics Monitoring System (BLMS) Design

3.1. Reference Implementation

The benefits and potential of blockchain technology to drive efficiency and value in the supply chain have been studied in previous sections; this section will present a roadmap for application. In order to demonstrate the technical architecture of a blockchain-based logistics monitoring system (BLMS), a reference implementation was designed and implemented. The purpose of the software was to provide a solution for parcel tracking and to provide an open and immutable history record for each transaction in the supply chain.

One classification of blockchain types is based on access to the system. According to Yeoh (2017), Peters and Panayi (2016) and Wu et al. (2017), there are two types of blockchain systems:

(1) Permissioned (private), where verification nodes are known and identified by a central authority or database, and various financial institutions are implementing private ledgers.

(2) Permissionless (public), where anyone can participate in the verification process without authorization. Computer resource utilization in this part is often rewarded.

(3) Hybrid, where both permissioned and permissionless ledgers are used in a solution. It is difficult to address the practical requirements of blockchain applications in reality by using completely public or completely private ledger architecture in the information exchange. It is necessary to coordinate both types of ledgers in a solution. For instance, a private ledger is used for sensitive data, while a public ledger is used for data that require a high trust level. Each stakeholder can design access limitation to information by the two types of ledgers, without reliance on central governance (Wu et al., 2017).

Currently, there are several open-source blockchain platforms, such as Hyperledge and Ethereum, amongst others. Hyperledger can be used as general purpose blockchain-based distributed ledger with the goal of improving many aspects of performance and reliability (Lin & Liao, 2017). However, it is a permissioned blockchain, with limited participants (Wst & Gervais, 2018).

In this particular research, permissionless Ethereum (public blockchain) was selected to handle the process. Ethereum is the most well-known open platform that offers decentralized virtual machines (VMs) to run smart contracts by a built-in general purpose (Turing-complete) scripting language, namely Solidity (Wood, 2014; Efanov & Roschin, 2018). Anyone can use Ethereum to develop a blockchain-based decentralized system at a low cost and on a per-contract and per-byte basis (Bocek et al., 2017). It is not owned or controlled by any organization, but by all the peers who run the Ethereum nodes. Any node can participate without additional permission and authorization. Applications and services created on Ethereum can automate and facilitate direct interaction between nodes across the blockchain network.

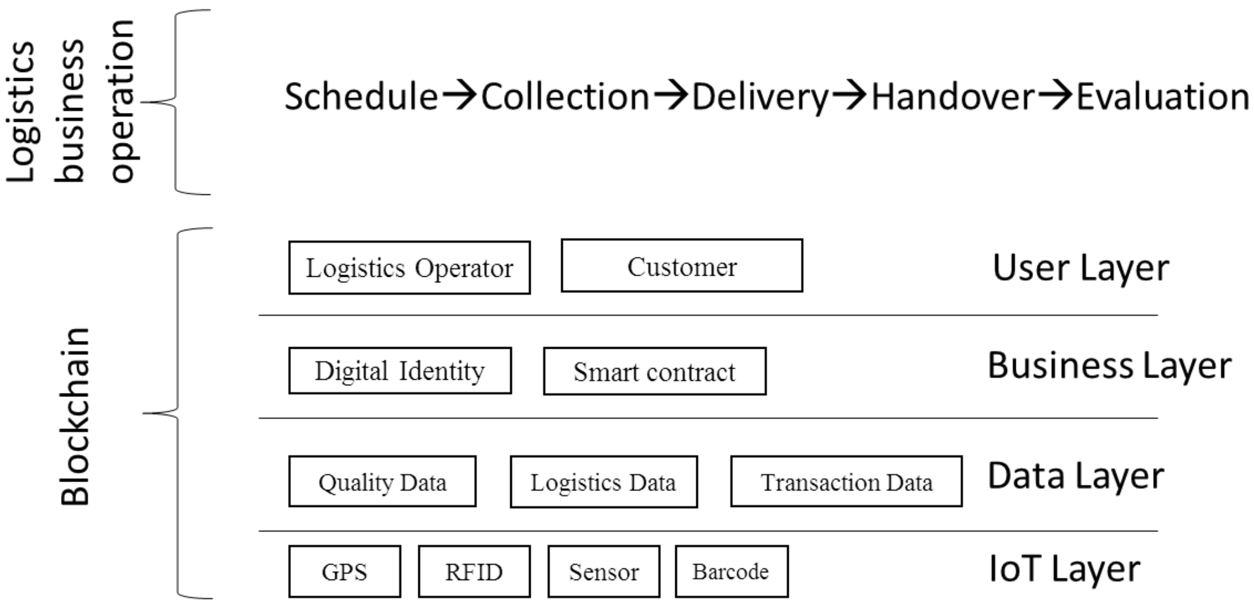


Figure 2. Blockchain-based logistics monitoring system architecture.

The framework and the corresponding system architecture are composed of four layers, as seen in Figure 2. This platform consists of several fundamental technologies and provides technical modules. This architecture is flexible and can be adapted based on realistic requirements.

- The bottom layer is the IoT layer: IoT devices enable real-time data collection. Blockchain offers a secure data sharing infrastructure in a distributed network, and it can cope with the data trust challenges.
- The second layer is the Data Layer. There are three kinds of data: quality data, logistics data, and transaction data. All the partners, including logistics operators and customers, keep a copy of the data on logistics operations.
- The third layer is the Business Layer. When the data is gathered and shared in a data layer, the data will be handled in the business layer in order to execute logistics monitoring and to improve the

efficiency of the logistics process. Therefore, digital identity is used to control the access authority to the data. Smart contracts are a user-defined program that can perform real time quality monitoring by using real time data.
- The top layer is the User Layer. This layer includes various users. Each partner can monitor the quality of logistics and performs various business activities with the support of blockchain.

Conceptually, blockchain is secured by achieving decentralized consensus and consistency. The records of logistics history are consistent and timely. They can be maintained without the involvement of a trusted mediator. Both customers and logistics operators have full access to data related to them (Esposito et al., 2018).

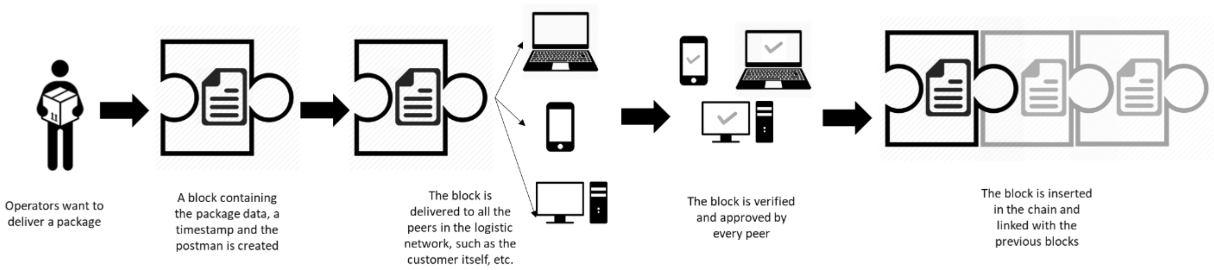


Figure 3. Steps of blockchain processing in logistics monitoring system.

Figure 3 describes the conceptual ecosystem of BLMS. This system mainly focuses on the activities of package delivery. The functionalities of the system consist of transaction entry for logistics operators. There are five main phases:

1. The operators are registered users. The user records a transaction with operator information, package information, location information and a timestamp. In addition, the transaction also includes the condition of the package, such as pickup, receiving, quality inspection, or final delivery.
2. When a new logistics transaction is created, a new block is presented and distributed to all peers in the logistics network.
3. All network participants receive the block for validation. After all of the participants have approved the new block, the system will insert it in the chain. This allows both customers and operators to achieve a global view of the logistics history in an efficient, verifiable and permanent way.
4. Once the block has been inserted into the chain, the data in any given block cannot be modified. Because the block is linked with a previous block, the modification can be easily detected. As block content is publicly accessible, logistics data need to be protected prior to the data being in the block (e.g. encrypted).
5. The approved block is added to the chain and the transaction is completed.

3.2. Software Implementation

The architecture of BMLS is structured into two parts: (1) back-end: Ethereum network to verify data, and (2) front-end: end-user interfaces to enter new transactions, as outlined in Figure 4. The key components of the system are:

- JavaScript-based client software implemented as an HTML web page, which operates as a user interface for the operator.
- Local web server software communicating with user interface, local database storage and local blockchain node.
- Local database is used to store completed transactions for quick search and retrieval.

- Blockchain is implemented on a server computer by using Ethereum Geth. This provides access to network processing blockchains.
- A distributed Ethereum network conducts verification tasks for each blockchain operation.

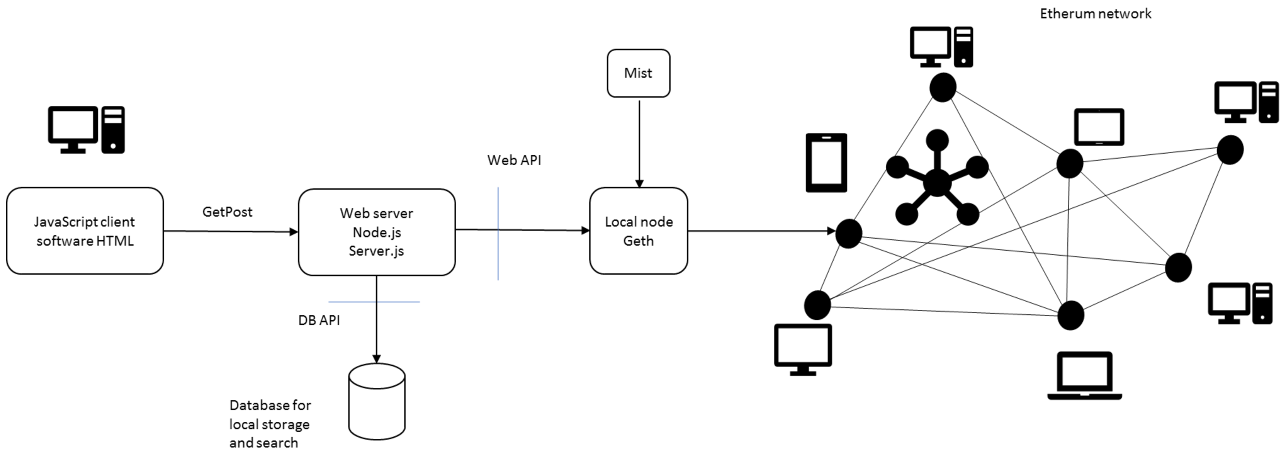


Figure 4. Implementation architecture.

The architecture supports distributed operations of transactions. Each block in the blockchain contains the data of the transactions as well as a link to the previous block. This chain of verifications can be checked by following the citations. Multiple server computers have processed the verification process, which guarantees the immutability of the data. Data can also be stored in distributed servers, but for reasons of practicality, local storage is used for quick search of package numbers.

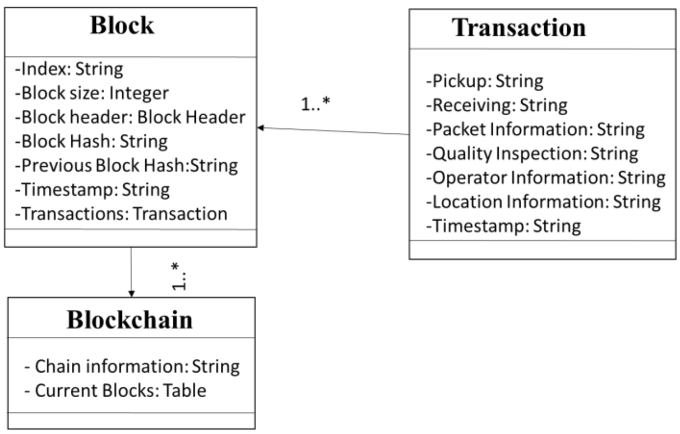


Figure 5. Domain model of blockchain-based logistic monitoring system.

This BMLS implementation has three main data objects: block, blockchain and transaction, as shown in Figure 5.

- Blockchain includes all the registered blocks of information. The blocks on the blockchain can be read by all participants in the network.
- A block is a container data structure that aggregates the transactions that are to be included in the blockchain. The block consists of size, header, containing metadata (a reference to a previous block hash, which connects the given block to the previous block in the blockchain, and timestamp), and a list of transactions.

- A transaction is a representation of a logistics record in the system. A transaction contains pickup, receiving, packet information, quality inspection, operator information, location information and a timestamp.

3.3. Practical Demonstration of the Application

Figure 6 illustrates the implementation of functions for handling the Ethereum by web3 API. In this reference implementation, the payload of the message consists of static data related to logistics transaction. However, further possibilities could be enabled by smart contracts, which technically are executable pieces of code which are programed in Ethereum. They can perform different functions when the conditions of a transaction are met, such as issuing a payment or transferring documents (Glover & Hermans, 2017).

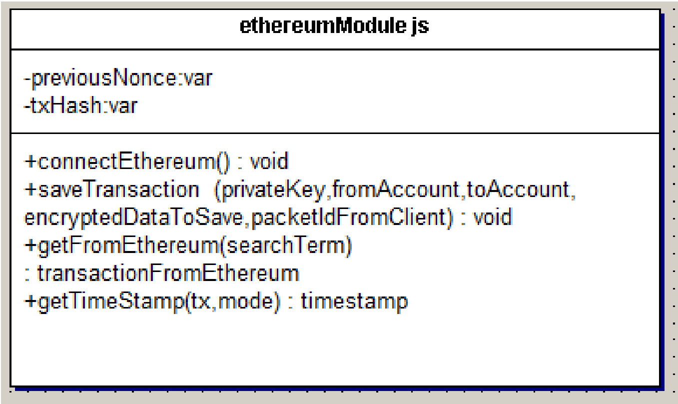
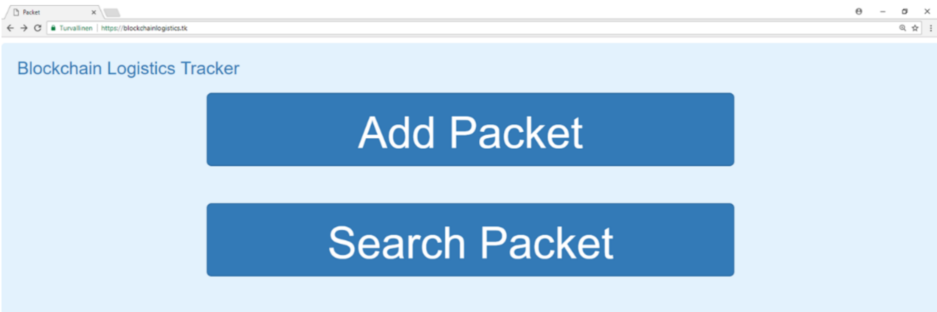
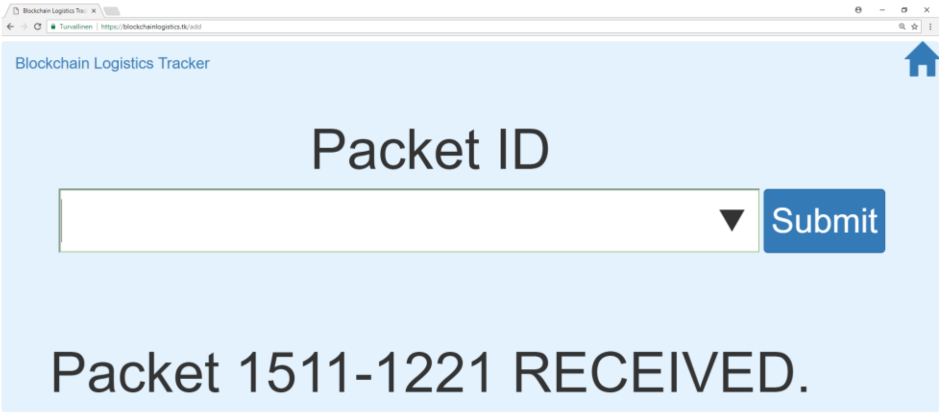


Figure 6. Software functionality to connect, search and save a transaction to the Ethereum network.

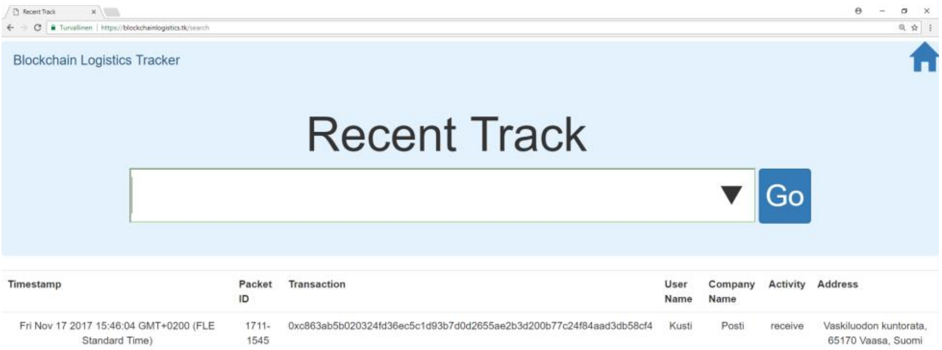
Each user can access the specific logistics transaction through a user interface in this system. The software application used by the users is configured for a specific digital profile of a packet. In practice, this kind of system should be developed by a group of trusted logistic operators, and be accessible for registered organizations and customers to access the logistic information. Figure 7a shows user interface examples of adding a new transaction and searching transactions. Figure 7b shows that the quick search function is performed from a local storage for transactions in an indexed search database. Figure 7c demonstrates the transaction information containing the data stored in InputData and has information for transparency and security.



a. User interface of function ‘Add Packet’ and ‘Search Packet’.



b. User interface of return transaction of quick search



c. Content of a transaction and data carried

Figure 7. User interface of reference implementation.

The experience from using BLMS system shows that software implementation is reasonably straightforward and good APIs are available. Processing speeds for transactions in the Ethereum network are often on a minute level and processing tasks require paying transaction fees. Blockchain solves the immutability part of the problem, but in practice replicated databases would be needed to have a proper response for user actions.

4. Discussion

Following the theoretical discussion in Section 2, a practical research approach was presented in Section 3. The BLMS in this research is a very explorative reference implementation. We chose this research approach because blockchain is still in its nascent stage. Our purpose is to set up a platform to meet the demand of supply chain related operations, and at the same time to guarantee the security and transparency of the record of all activities.

However, due to some challenges and obstacles during implementation, we find that the transition from traditional supply chain to blockchain-based supply chain is not smooth. We have identified several reasons:

1. The lifecycle of development and implementation is very long. Companies must have full knowledge of and capability in blockchain to start the project. Moreover, blockchain is still in its early stage in terms of industrial applications. It is full of uncertainty, such as whether blockchain is suitable for specific industries, whether there is a copyright problem, etc.
2. In addition, the competencies and the cost of practitioners are both at a high level. Practitioners need long-term training and technical development. Furthermore, it is important to realize that blockchain-based industrial solutions should start from the stakeholders' willingness to collaborate and be involved.

They must reach a consensus on building blockchain knowledge and capabilities with focus on driving value for all stakeholders. So it is critical to create a culture of collaboration.
3. Scalability is holding back early adoptions of blockchain in supply chains or in other similar areas. By definition, every computer connected to the network needs to process the transactions. Organizations have to sacrifice efficiency to obtain security. Therefore, there is a high demand in terms of the technical infrastructure which will be more expensive than the traditional approach.
4. Current data privacy is not applied to the transaction data. Partners are permitted to use such information without any specific data protection. Therefore, it is very important to create certain boundaries to potential applications of blockchain technology. Also, certain parts of shipment details may be referred from blockchain to an external system link.

The above problems need not only practical verification and improvement, but also in-depth thinking and research by the academic community in the future.

In this study, one limitation of this prototype of BLMS is that it is deployed as an independent platform with a stand-alone network. Therefore, it is incompatible with other applications on different deployments of the platform elsewhere. It is important in the future to develop the ability for multiple applications to run across a common layer of identity, consensus and governance. Once connected to the infrastructure, companies would then be able to collaborate with multiple partners, for different purposes, and under different regulation frameworks. All the business activities can happen simultaneously with guaranteed security, trust and privacy.

Table 2 presents a performance analysis of different tracking technologies for supply chain. This comparison provides a clear view in the context of selection on distributed platform.

Table 2. Comparison of tracking technologies.

	Centralized database	Blockchain distributed	Hybrid
Tag content	ID number	ID number and transaction blocks	ID number and transaction blocks
Content storage	Centralized relational database	Decentralized storage of blocks on each server	Transaction data stored on decentralized servers, generic product data stored on centralized servers
Security	Non-redundant	Redundant, Immutable data storage, based on multiple servers	Adjustable, but compromise of centralized and pure blockchain
Local storage	High quantities of relational data as needed	500 – 4000 MB on each server for transaction data	A combination of best parts
Performance	ms level response time	30 – 500 sec response from the network without local cache	Security related transactions are limited by blockchain performance
Cost	Single server needed	Group of servers hosted by interest group needed	High, several servers needed

According to the characteristics of blockchain, stakeholders who use this BLMS will benefit more when the number of participating users grows in this community. A powerful network effect is triggered in the supply chain when stakeholder adoption reaches a critical mass. As more and more supply chain stakeholders participate, blockchain becomes more valuable and more authentic, evolving into an industry practice. However, it will be difficult at first to obtain stakeholder commitment because of differing levels of digital readiness and the initial requirement to recognize the mutual benefits of blockchain-based collaboration. This will be particularly tricky when there are legacy processes, regulations and laws governing various aspects of the business, as stakeholders will incur costs when migrating from legacy systems and integrating with new systems and practices.

In future, many organizations, not only in the private sector but also public departments, will put effort into the blockchain based logistics system, due to the competitive nature of business. Therefore, it is important to determine standards and agreements to ensure the interoperability between different blockchain-based platforms. The Blockchain in Transport Alliance (BiTA) is an organization that enables blockchain adoption and works on standards development in the transport and logistics industry. Its main purpose is to tackle this kind of challenge (Kückelhaus & Chung, 2018, p.7).

5. Conclusions

Currently, there are several challenging features regarding the supply chain, making it very difficult to manage. For instance, multiple parties are involved in the supply chain, a shared common database is needed, and also the transactions are rarely changed once recorded in the ledger. Therefore, the supply chain can be increasingly streamlined using digital infrastructure environment like blockchain, where all involved parties will be able to share and access product- related information in real-time such as invoice, checking the latest status, and payment in a transparent manner. Participants are able to continuously monitor goods and transactions digitally in detail. Such an inclusive infrastructure relies on a shared ledger that provides any supply chain-related information and ensures global authenticity and security for data and information at the same time. This significantly reduces complexity of today's systems (Orman, 2016).

However, logistics and supply chain management research on blockchain is still in its infancy and ought to consider possible applications. Many logistics operators, especially small and medium-sized companies, state that they have little knowledge about blockchain and that they consider the impact of blockchain as a threat (Hackius & Petersen 2017). In order to gain their own first-hand experience, companies should implement small-scale experiments (Hackius & Petersen, 2017).

In order to increase understanding of blockchain, a prototype of blockchain-based logistic monitoring system (BLMS) has been developed in this research. Within this BLMS, logistic data was gathered and shared with a blockchain solution. The functionality of the system enables customers and logistic operators with all other partners to track and trace their packages within the ecosystem and also obtain insight into their own package information from the system.

The presented reference architecture demonstrates how blockchain can be implemented in the operational and supply chain context by using software components. The Ethereum framework was chosen because that application development is supported by powerful tools. Other blockchain solutions could have been used to achieve the same functionality, or then the entire blockchain infrastructure, including public-private keys, peer to peer network and hashing algorithms, could have been made from scratch.

Our results show that, unlike other IT-architectures, blockchain technology is a promising technology platform for creating transparency, automation and trust for the supply chain. Although a new solution has been presented, it still lacks a concrete evaluation on its effectiveness. This implementation can be extended in the future. A scenario analysis or even a simulation would be appreciated to measure both the qualitative and quantitative aspects. This would be beneficial for further developments of blockchain applications and widespread adoption in the supply chain.

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