International Journal of Recent Engineering Research and Development (IJRERD)
ISSN: 2455-8761
www.ijrerd.com || Volume 06 – Issue 08 || August 2021 || PP. 11-20

Food Supply Chain Traceability Architecture Based on Blockchain Technology

Burak Köse[1], Semih Utku[1]
[1]*Departmant of Computer Engineering, DokuzEylul University, Izmir, Turkey*

Abstract: Nutrition is one of our most important needs. The nutritional needs of societies are provided by food supply chains. Transparency and traceability of food supply chains are very important, because foods are a factor affecting human health. There are many known problems in today's food supply chains, such as food fraud. Popular and emerging blockchain technology is an effective tool that can be used to eliminate these problems. In this study, a blockchain supply chain system is designed by using Hyperledger Fabric platform. On the other hand, how the blockchain solutions overcome to these problems are examined. Different blockchain types and platforms are compared. Obtained results show that Hyperledger Fabric is a suitable and effective platform to solve food supply chain problems. An exemplary system is designed and developed with Fabric.
Keywords: Food Supply Chains, Food Traceability, Blockchain, Hyperledger Fabric.

1. INTRODUCTION

One of the most striking features of the blockchain is that the transactions performed in a blockchain system do not need a centralized structure and that the data is kept immutable. The blockchain network has a fully distributed architecture, thus avoiding single point failure, which is the biggest problem of central systems. The main problem of distributed systems such as blockchain is how to achieve the reliability of the overall system despite the existence of erroneous transactions. If any node in the network fails, other nodes in the system should not be affected and the system should continue to run. The consensus mechanism, which is the fault-tolerance mechanism, is used for this. In this way, it is ensured that the data in the system remains secure and the nodes work together. Although there has been a lot of research and work on solving the problems of food supply chains with blockchain, there is little experience in implementing blockchain in real-world software applications.

After the discovery of the Bitcoin currency, blockchain technology attracted attention. Blockchain has proven that it can produce solutions to many problems with its fully distributed architecture and immutable data structure.

Nowadays, although it is on the agenda with crypto currencies, it is important candidate for produce solutions on many different fields such as financial services, reputation systems, internet of things and supply chains thanks to the innovative features it brings with it.

1.1. Problem Definition

Nutrition is one of the basic needs of people. With the increasing population, the problem of meeting the food needs emerging worldwide emphasizes the importance of food supply chains. The food supply chain covers the entire process from the production of the food to its consumption.

Food quality and reliability are the most critical features of this chain. Food is one of the factors affecting consumer health. The management of food safety risks generally focuses on the dangers that occur naturally or unintentionally in food production and supply processes. However, deliberate behavior in the production process in order to gain economic profit causes serious quality and safety problems [1].

Although food fraud seems to be the problem of today, it is a very old problem. This topic has historically been studied by considering real events on different products. As a result of the examinations, it was found that the resources provided for the application of science and the inspections performed were insufficient [2]. The sanctions of authorities against fraudulent and fraudulent actors will ensure that the food supply chain is as safe as possible.

Supply chains must be fully traceable to ensure food quality. However, due to the natural nature of the supply chain, it is difficult to ensure full traceability. The supply chain consists of many stakeholders. To monitor a product along its entire supply chain, all stakeholders in the chain must implement traceability solutions. The weak communication between stakeholders is one of the important problems of the supply chain. A comprehensive review has been made on cooperation in the supply chain, a significant number of cooperation elements have been identified, and studies have been made on the performance and efficiency of cooperation on the supply chain [3]. All collaborators in the supply chain need to be in cooperation. Traceability will increase

communication and trust not only among consumers but also among stakeholders. It will also ensure that the intervention of unknown and uncontrolled third parties in the process is avoided.

Today, with the development of technology and the increase of consumer awareness, food quality and reliability have become very important for consumers. The coverage of many food scandals in the news and diseases caused by foods that could harm consumer health have reduced confidence of consumers in food production and supply chains [4].

1.2. How Does Blockchain Solve These Problems?

To eliminate the problems mentioned above, full traceability and transparency of food supply chains should be ensured. In this way, a quality and reliable food production and supply environment is created that does not risk consumer health. With the rapid development of technology, many technologies have been applied on the traceability of supply chains. Most of these applied technologies and studies have adopted the centralized architecture. Centralized systems bring some problems with them. Single point failure is one of the most important known deficiencies of these systems. In addition, since identity management is managed by a single organization, it offers a monopolistic approach to problems such as fraud. Since the supply chain consists of multiple stakeholders, centralized systems are insufficient to solve the problems of the complex process. Blockchain technology has become an effective tool for solving these problems with its underlying distributed architecture and many features. In addition, keeping data immutable in the blockchain system brings transparency and reliability. Thanks to these features, it has created a lot of excitement about solving problems in food supply chains and has become the focus of many researchers.

2. RELATED WORKS

Most of the systems developed to solve the problems of food supply chains have a centralized architecture. Due to this structure, current supply chains operate linearly from the production process to the consumers. Data are centralized in each stakeholder of the supply chain. One stakeholder cannot see actions from other items. This causes the source of the food to be unverifiable. Since each stakeholder keeps the data in its own system, it cannot be ensured that the data are reliable [5]. Blockchain, along with its fully distributed architecture, is the most important candidate for solving these problems. Many studies have been carried out to measure the applicability of blockchain to food supply chains. Nevertheless, these researches cover a small part of the research on blockchain [6]. Jiang Duan et al conducted extensive research based on content analysis to measure the acceptance of Blockchain technology for the supply chains on food [7]. Most research and studies show that blockchain technology has number of advantages and disadvantages due to its nature.

Table 2: Benefits and challenges of blockchain

Benefits	*Challenges*
Traceabilit	Lack of understanding
Transparen	Immature technology
Reliability	Participant cooperation
Sustainabil	Trade secrets
Efficiency	Raw data manipulation

Food supply chains consist of many stakeholders. Blockchain provides transparency for all actors. Data is stored as irreversibly in blockchain. This creates a unique level of reliability that accommodates with a more retainable industry. Blockchain helps collaborating actors to consolidate their communication with existing customers and draw the attention of new ones [8]. Niels Hackius and colleagues worked on the online survey. In this study, they identified logistics experts as the target group. With the survey they conducted, they researched the obstacles in supply chains and asked the experts about their expectations from blockchain technology. As a result of this field research, they found that the participants responded positively blockchain which brings solutions with new features [9].

HACCP (Hazard Analysis and Critical Control Points) is a systematic approach that focuses on food safety in detail and prevents dangers that will threaten human health. The main purpose of the standard is to make food production and consumption the healthiest. Therefore, it prioritizes social welfare and hygienic requirements [10]. Feng Tian created a food supply chain traceability system that could provide an open information platform for all supply chain members for real-time food tracking based on HACCP, blockchain and Internet of Things. With a scenario, they examined the system from all angles. They proposed that it would provide all supply chain members with real-time information on the safety status of food products, greatly

reducing the risk of centralized information systems and making them more secure, distributed, transparent and collaborative. They argued that system could significantly increase the efficiency and transparency of the food supply chain, which would obviously increase food security and rebuild consumer confidence in the food industry [11].

With the development of technology, much progress has been made in the field of IoT. Thanks to this, the use of IoT in food supply chains has increased. However, existing IoT-based traceability and provenance systems are built on centralized infrastructure. To get rid of the problems caused by this structure, Pincheira Caro et al developed the blockchain-based Agri Block IoT product in their study. They defined the model they created within a specific field system. They installed two different blockchain applications on this area, Ethereum and Hyperledger Sawtooth. They evaluated 2 applications in terms of performance, latency, CPU, and network usage. As a result of their analysis, they concluded that the Hyperledger Sawtooth-based application performed better in terms of metrics compared to the Ethereum-based application. But in line with the needs, they stated that Ethereum's software maturity is high, more participatory, scalable, and reliable, so performance can be ignored. They emphasized that IoT devices have processing power due to their small size, and they said that Hyperledger saw tooth could be a better solution at this point [12].

Although blockchain technology is evolving, it is underutilized in existing software applications. Therefore, we have little experience with the application of this technology. Xiwei Xu et al developed the blockchain system called OriginChain. In a system using a central database, they removed the central database and used blockchain instead. With this change, they restructured the system. At the design phase of blockchain, they applied the blockchain approach recommended by the software architecture community. They compared the read-write performances of the Ethereum-based blockchain application they established with the local and remote database. As a result of their analysis, they found that every node has a copy of the block chain, so there is no performance loss in reading transactions. However, due to the consensus process, they observed that the writes were very slow compared to local and remote databases [13].

Works on food supply chains is limited by most of his theoretical applications and unstructured experiences. Blockchain types and platforms have different advantages and disadvantages. Considering the needs of the field, these should be examined and the platform that will be the right solution for the need should be worked on. This article examines blockchain types and platforms. The blockchain platform to be used was decided and a sample application was developed.

3. WHICH BLOCKCHAIN IS APPROPRIATE FOR SOLUTION?

The main purpose of the blockchain is to carry out the transactions and the information exchange between the nodes over a secure network and keep them unchangeable. Blockchains differ due to the structure and configurations they use while achieving this goal. There are 2 different block chains, public and private. The comparison of these is given in table 2.

3.1. Public Blockchain

Anyone with internet access can join the public blockchain. There are no restrictions. All stakeholders participating in the network can access the records available on the network [14]. They are also authorized to mining or verify transactions. Each authorized node has a copy of the blockchain data. This makes the entire system completely open and transparent. It is safe because it has a completely distributed infrastructure. Since it is a large network of many nodes, the number of transactions per second is low. For this reason, its scalability decreases [15]. Proof of work is used to ensure trust, as it is made up of completely anonymous nodes. Although providing anonymity is an advantage, the time and energy required for proof of work is a disadvantage.

3.2. Private Blockchain

The private block chain is only accessible to verified participants. Only stakeholders can access the records on the network. Proof of work is not needed as all participants are verified when joining the network. It also saves time and energy expenditure. For this reason, the number of transactions per second is high and the scalability of these networks is high [16]. There are designated permissions to perform certain activities on the network. This indicates the role meaning for the participants. The roles of the participants and their roles in the network may be different. Identity management can be centralized, because of participation process in the network is managed by the organization. The occurrence of such a situation adversely affects security.

Table 2: Comparison of blockchain types

	Public	*Private*
Characteristics	• Truly decentralized • Anonymity • Transparency • Immutable • Enhanced security	• Varying decentralization • Governance • Customizability • Efficient • Anonymity • Transparency
Advantages	• Open to everyone • Bring trust to users • Offers high security	• Extremely fast output • Scalable network • Offers energy efficiency
Disadvantages	• Slow transactions • Harder to scale • Not energy efficient	• Not truly decentralized • Less transparent • Partial immutability

The most important point of blockchains is the consensus mechanism. These mechanisms are used to come to a consensus about all the operations taking place on the network and the current state of the system. There are 3 commonly known consensus mechanisms.

3.3. Proof of Work (PoW)

Mining is required to validate a new process. Miners solve a difficult problem and verify the process by performing this excavation. This mechanism is a system in which miners holding most of the processing power have more say in the network and therefore gain more returns [17], [18]. As an example, Bitcoin and Ethereum use this mechanism.

3.4. Proof of Stake (PoS)

Users who want to be able to verify a new transaction and get a share of the revenue must lock their cryptocurrency assets to be used for verification. In this locking process, which is called "staking" (getting a share from the income), the amount to be used for this transaction in the wallet cannot be withdrawn from the wallet until it is unlocked and is marked as the user's share on the network [17], [18].

3.5. Practical Byzantine Fault Tolerance (pBFT)

In networks with distributed architecture, some nodes may fail or be malicious. The ability to reach consensus even when faced with such a situation is called BFT. It is derived from the Problem of Byzantine Generals. For a new transaction to be included in the ledger, at least 2/3 of the approved spouses must give the same response. It is especially used in permissioned blockchains [18].

Table 3: Comparison of PoW, PoS, and pBFT

	PoW	*PoS*	*pBFT*
Blockchain Type	Permissionless	Both	Permissioned
Transaction Rate	Low	High	High
Energy Consumption	High	Low	Low
Trust Model	Untrusted	Untrusted	Semi-trusted

There is an inverse proportion between performance and scalability in blockchains. Performance decreases as scalability increases. Scalability and security are at the forefront in public blockchains. For this reason, the number of transactions per second is low. Bitcoin and Ethereum are platforms that make scalability an advantage using PoW. But if we look at the Hyperledger fabric, it used pBFT to increase performance [19].

Anonymity in the blockchain indicates whether the identity of the user joining the network is transparent. Wallet address or alias that represents a person on public blockchains. In private blockchains, by contrast, the participants joining the network know each other.

Blockchain platforms differ from each other by many feature differences. Each platform is produced to serve different purposes. For this reason, it is necessary to understand the features of the platform to be used before generating a solution.

Table 4: Comparison of blockchain platforms

	Bitcon	*Ethereum*	*Hyperledger Fabric*
Permission Restrictions	Permissionless	Permissionless	Permissioned
Accessibility	Public	Public or Private	Private
Consensus	PoW	PoW or PoS	Pluggable
Node Scalability	High	High	Low
Performance Scalability	Low	Low	High
Native Cryptocurrency	Bitcoin	Ether	-
Smart Contracts	-	Can be programmed in Solidiy	Can be programmed in Golang, Nodejs, java

Food supply chains extend from the production stage of the food to the consumption stage. For this reason, there are many stakeholders forming the chain. The role and identity of each stakeholder involved in this process is different. Considering these requirements, private blockchains are the most suitable in terms of structure and configuration.

Hyperledger Fabric is designed modularly. Components such as consensus and subscription services are used as plug and play. Modularity allows to choose the consensus mechanism to be used. In this way, it offers solutions not only to financial services but also to many areas. While providing privacy with its network structure, it also provides a solution that is scalable in terms of performance. Also, all previous blockchain systems have taken the order-execution architecture as the basis. The order-execute architecture limits scalability, requiring transactions to be executed sequentially and approved by all peers. Fabric offers us different architecture and follows execute-order-validate architecture instead of standard order-execute architecture. With this architecture, it overcomes some problems such as resource consumption [20]. In addition, the fabric network allows multiple different organizations, channels, and smart contracts. Considering its structure and properties, we advocate that Hyperledger fabric is a suitable and effective platform to solve the problems of food supply chains.

4. FOOD SUPPLY CHAIN TRACEABILITY ARCHITECTURE BASED ON BLOCKCHAIN TECHNOLOGY

We created a scenario on shipment. In the scenario, we aimed to track all operations from the beginning to the end of a product shipment through the block chain. We used Hyperledger Fabric Nodejs SDK to realize this scenario. The application we have developed consists of 2 layers. These are the network and application layer. Network layer represents the blockchain. In this layer, there are network elements, smart contract, and client SDK that we will use to access the network. In the application layer, there is a web API that accesses the blockchain and an interface that uses this API.

Table 5: Used technologies for each layer

Layer	*Used Technologies*
Blockchain Network	• Fabric Network • Chaincode • Smart Contract • CouchDB • Docker • Docker Compose
Web API	• MongoDB • NodeJS • ExpressJS
Web UI	• React • HTML5 • CSS3 • JavaScript

4.1. Nodes in Blockchain Network

We determined in channel configuration that the organization definition and the role of the organization. We created 1 organization for the test application. We created a channel and added other nodes to this channel. One of the nodes is an endorser peer that includes Ledger and smart contract. Runs the smart contract and confirms transactions. But it does not update the ledger. Anchor peer is required for larger networks. Anchor peer, if there is more than one peer of the same organization, they oversee publishing the updates on the network to other peers. Since there is only one peer in our scenario, there is no need for anchor task. Orderer is responsible for the consistency and updating of Ledger. The certification authority creates the necessary certificates for the organization's nodes, administrators, definitions, and applications. The client application interacts with the blockchain and can send new transactions to the network or query the ledger.

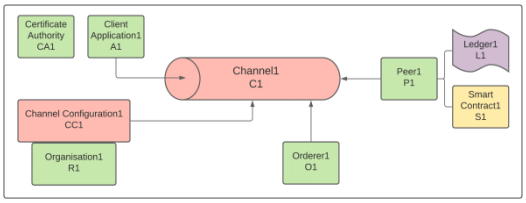

Figure 1: The structure of blockchain network

4.2. Smart Contract and Chaincode

The smart contract defines the working logic of the new block and transaction to be added to the ledger.

Table 6: Details of smart contract

Function	*Input*	*Output*	*Description*
Query Shipment	ShipmentId	Shipment with transactions	Return specific shipment
Query All Shipments	-	All shipments with transactions	Returns all shipments
Add Shipment	shipment	-	Adds new shipment
Add Shipment Transaction	ShipmentId, transaction	-	Adds new transaction to specific shipment

4.3. Web API

Web API has been developed with NodeJS. The client application is used by this API. Thanks to this, API can interact with the blockchain. It contains workflow logic for end-users to use. Users authorized to access API can use client SDK in line with their permissions. While the client application determines the operation capability of the organization on the network, the web API determines the claims and roles of the users of the organization.

4.4. Web UI

It is an interface project developed to interact with the web API. It has been developed for end-users to view shipment and transactions and to add new transactions. End-users can log in from this interface and act in line with their authorization.

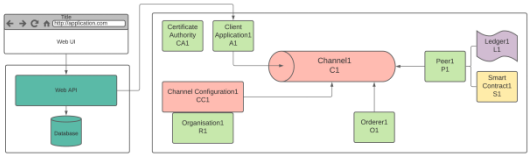

Figure 2: The general architecture of the system, from end-user to the blockchain network

5. CHALLENGES AND FUTURE WORKS

5.1. Challenges

We can examine challenges in 2 different groups.

First, the general structure of food supply chains. Full traceability is difficult to achieve due to the nature of food supply chains. During the process, it is almost impossible to monitor every indicator and process with sufficient precision [21]. Another issue is that supply chains consist of many stakeholders. Each stakeholder forming the chain should have the same responsibility and carry out the whole process in a technologically traceable, reliable, and transparent manner. At the same time, all stakeholders must trust each other. Cooperation between commercial partners is difficult [4].

Second is blockchain technology. Blockchain is still an emerging technology. Although it brings advantages, there are also disadvantages [22]. Blockchain technology needs to be used and developed more, and the knowledge base needs to grow. However, blockchain has proven that it can solve many problems at the point it has reached today. The blockchain network is distributed and consists of many peer nodes. Therefore, the network is difficult to set up. To facilitate these processes, large companies such as IBM, AWS, Google

offer BaaS (blockchain as a service) service for a certain fee. The platforms supported by each are different [23]. Difficulty to set up blockchain network are an obstacle for large-scale work to be done.

5.2. Future Works

The application we have developed contains a single organization. In future studies, a multi-organizational infrastructure can be provided. The reliability of the blockchain is directly proportional to the number of nodes. The higher the number of nodes, the higher the reliability. Thanks to the flexible infrastructure of Hyperledger Fabric, networks with many organizations, various channels and smart contracts can be established. The limitation of our study is that the network is installed on a machine. To overcome centralization, the system must be distributed. Fully custom and distributed network can be created with Docker-swarm or BaaS can be used.

6. CONCLUSION

Our nutritional needs are met through food supply chains. Many studies show that there are problems such as traceability, reliability, and transparency in food supply chains. Many solutions have been produced to overcome these problems. Most of these solutions are traditional solutions based on centralization. However, supply chains, by their nature, consist of many stakeholders. For this reason, the real solution can be reached through distributed systems. Blockchain is the most popular technology of today's distributed systems.

With the discovery of Bitcoin, a lot of research has been done on blockchain which has attracted a lot of attention. Feasibility studies show that blockchain technology is an effective tool not only in financial services but also in other fields. From this perspective, blockchain is the most popular candidate for the solution of food supply chain problems.

Most of the solutions produced in the studies so far are theoretical and not applied to real life. Blockchain technology brings many advantages with it. But its disadvantages should not be ignored. There are some challenges to be resolved. For this reason, the type and platform of the blockchain used when producing solutions with this technology should be thoroughly investigated. The right choices should be made by analyzing the requirements correctly and comparing the advantages and disadvantages. Because of that, we investigated the blockchain types and platforms in line with the food supply chains needs in our study. We have suggested that permissioned blockchains and Hyperledger Fabric will be an effective tool for solving food supply chain problems. We created an architecture and developed an application with Fabric. Fabric provides convenience to developers with support for many popular languages. Thanks to its infrastructure and modularity, it becomes the effective tool we seek to solve food supply chain problems.

7. REFERENCES

[1] S. Tähkäpää, R. Maijala, H. Korkeala, en M. Nevas, “Patterns of food frauds and adulterations reported in the EU rapid alarm system for food and feed and in Finland”, Food Control, vol 47, bll 175–184, 2015, doi: 10.1016/j.foodcont.2014.07.007.

[2] P. Shears, “FOOD FRAUD-A CURRENT ISSUE BUT AN OLD PROBLEM”, 2008.

[3] J. Coveney, “Food and trust in Australia: Building a picture”, Public Health Nutr., vol 11, no 3, bll 237–245, Mrt 2008, doi: 10.1017/S1368980007000250.

[4] M. Barratt, “Understanding the meaning of collaboration in the supply chain”, Supply Chain Manag., vol 9, no 1, bll 30–42, 2004, doi: 10.1108/13598540410517566.

[5] R. Casado-Vara, J. Prieto, F. De La Prieta, en J. M. Corchado, “How blockchain improves the supply chain: Case study alimentary supply chain”, in Procedia Computer Science, 2018, vol 134, bll 393–398, doi: 10.1016/j.procs.2018.07.193.

[6] D. Dujaken D. Sajter, “Blockchain Applications in Supply Chain”, 2019, bll 21–46.

[7] J. Duan, C. Zhang, Y. Gong, S. Brown, en Z. Li, “A content-analysis based literature review in blockchain adoption within food supply chain”, International Journal of Environmental Research and Public Health, vol 17, no 5. MDPI AG, Mrt 01, 2020, doi: 10.3390/ijerph17051784.

[8] J. F. Galvez, J. C. Mejuto, en J. Simal-Gandara, “Future challenges on the use of blockchain for food traceability analysis”, TrAC - Trends in Analytical Chemistry, vol 107. Elsevier B.V., bll 222–232, Okt 01, 2018, doi: 10.1016/j.trac.2018.08.011.

[9] W. Kersten, W. Kersten, T. Blecker, C. M. Ringle, enepubli GmbH, Proceedings of the Hamburg International Conference of Logistics (HICL)/Digitalization in Supply Chain Management and Logistics Smart and Digital Solutions for an Industry 4.0 Environment. .

[10] S. Mortimoreen C. Wallace, HACCP: A practical approach. Springer Science \& Business Media, 2013.

[11] Tian, “ePub WU Institutional Repository Feng Tian An information System for Food Safety Monitoring in Supply Chains based on HACCP, Blockchain and Internet of Things Thesis Original Citation: An

information System for Food Safety Monitoring in Supply Chains based on HACCP, Blockchain and Internet of Things".

[12] M. P. Caro, M. S. Ali, M. Vecchio, en R. Giaffreda, "Blockchain-based traceability in Agri-Food supply chain management: A practical implementation", in 2018 IoT Vertical and Topical Summit on Agriculture - Tuscany, IOT Tuscany 2018, Jun 2018, bll 1–4, doi: 10.1109/IOT-TUSCANY.2018.8373021.

[13] X. Xu, Q. Lu, Y. Liu, L. Zhu, H. Yao, en A. V. Vasilakos, "Designing blockchain-based applications a case study for imported product traceability", Futur. Gener. Comput. Syst., vol 92, bll 399–406, Mrt 2019, doi: 10.1016/j.future.2018.10.010.

[14] D. Guegan, "Public Blockchain versus Private blockhain".

[15] A. Chauhan, O. P. Malviya, M. Verma, en T. S. Mor, "Blockchain and Scalability", in Proceedings - 2018 IEEE 18th International Conference on Software Quality, Reliability, and Security Companion, QRS-C 2018, Aug 2018, bll 122–128, doi: 10.1109/QRS-C.2018.00034.

[16] S. Pongnumkul, C. Siripanpornchana, en S. Thajchayapong, "Performance Analysis of Private Blockchain Platforms in Varying Workloads".

[17] S. S. Panda, B. K. Mohanta, U. Satapathy, D. Jena, D. Gountia, en T. K. Patra, "Study of Blockchain Based Decentralized Consensus Algorithms", in IEEE Region 10 Annual International Conference, Proceedings/TENCON, Okt 2019, vol 2019-October, bll 908–913, doi: 10.1109/TENCON.2019.8929439.

[18] W. Dren A. Baliga, "Understanding Blockchain Consensus Models", 2020.

[19] M. Sethumadhavan, "On Blockchain Applications: Hyperledger Fabric And Ethereum".

[20] E. Androulaki et al., "Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains", Jan 2018, doi: 10.1145/3190508.3190538.

[21] E. Golan, B. Krissoff, F. Kuchler, L. Calvin, K. Nelson, en G. Price, "Traceability in the U.S. Food Supply: Economic Theory and Industry Studies".

[22] Z. Zheng, S. Xie, H. Dai, X. Chen, en H. Wang, "An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends", in Proceedings - 2017 IEEE 6th International Congress on Big Data, BigData Congress 2017, Sep 2017, bll 557–564, doi: 10.1109/BigDataCongress.2017.85.

[23] M. M. H. Oniken M. H. Miraz, "Performance Analytical Comparison of Blockchain-as-a-Service (BaaS) Platforms", in Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST, 2019, vol 285, bll 3–18, doi: 10.1007/978-3-030-23943-5_1.