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# A Procedure for Tracing Supply Chains for Perishable Food Based on Blockchain, Machine Learning and Fuzzy Logic

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**Abstract:** One of the essential points of food manufacturing in the industry and shelf life of the products is to improve the food traceability system. In recent years, the food traceability mechanism has become one of the emerging blockchain applications in order to improve the anti-counterfeiting area's quality. Many food manufacturing systems have a low level of readability, scalability, and data accuracy. Similarly, this process is complicated in the supply chain and needs a lot of time for processing. The blockchain system creates a new ontology in the traceability system supply chain to deal with these issues. In this paper, a blockchain machine learning-based food traceability system (BMLFTS) is proposed in order to combine the new extension in blockchain, Machine Learning technology (ML), and fuzzy logic traceability system that is based on the shelf life management system for manipulating perishable food. The blockchain technology in the proposed system has been developed in order to address light-weight, evaporation, warehouse transactions, or shipping time. The blockchain data flow is designed to show the extension of ML at the level of food traceability. Finally, reliable and accurate data are used in a supply chain to improve shelf life.

**Keywords:** perishable food; blockchain; fuzzy logic; machine learning; traceability system



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## 1. Introduction

The perishable food supply chain (PFSC) is one of the challenging areas in the food industry sector, but supply chain management is trying to achieve better quality for satisfying the strict provisions [1]. Food safety is facing serious problems for purchasing to consumers due to the COVID-19 issues all over the world. On the other side, they are more sensitive to food quality, origin, and shipping rules. Based on this situation, there is a need for a food traceability system to over-change the supply chain sector. The proposed model was formulated based on two main perspectives, as following [2]: information and communication technologies and chemical analysis. These are the suitable tools for identifying, tracing, and monitoring the purchased item in the supply chain. Based on the growth of e-commerce business, sharing information in the supply chain is difficult, due to the perishable food international trades, customer behavior, system efficiency, reliability, etc. Blockchain and other Distributed Ledger Technologies (DLTs) are predicted in many industries, because of the allowance of storing the dataset that can be switched between organizations that do not trust each other [3,4]. Similarly, blockchain is still considered under development technology [5,6]. Some of the trust required applications in blockchain have already been already developed [7]. Another aspect of blockchain and DLT can design the smart contract that can define the self-sufficient decentralized codes, which contains the rules and conditions for business processes. The smart contract defined codes are based on legal terms that control the practicable programs' physical and digital objects. Figure 1 shows the PFSC recent general six major supply chain parts and two main issues in the food traceability system. The first step is the sufficient description of traceable resource units (TRUs) in order to identify the traceability system objects, production unit, logistic unit, etc. for supply chain proceeding and raw supplier to end consumers [8].

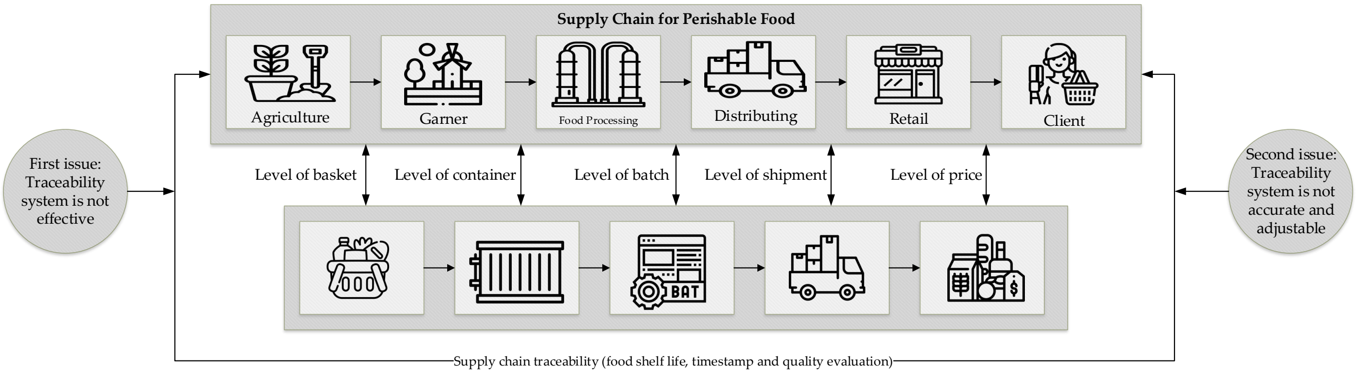



**Figure 1.** Perishable Food Supply Chain Challenges.

TRUs are one of the food traceability system required components that consider the food packaging and identification in special supply chains. Furthermore, the development of IoT technology in food-related areas makes the traceability system more complicated. Based on these issues, the traceability process becomes time-consuming. Another traceability system is related to the modern or business system. In this case, the customer cannot check the item, and the decision relies on the information that is provided by companies. The decision making for the product quality, e.g., shelf life, is also lacking. The blockchain system considers a practical environment for the food traceability system that is based on low-cost implementation. There is no ability to utilize the raw data, which causes trust in the supply chain network. Similarly, the blockchain system provides monitoring and product tracking functions to handle the supply chain processes. The main view of the blockchain system expands the cryptocurrency rather than supply chain traceability. Thus, the mechanism is inconvenient and not enough for supply chain network achievement.

The main contribution of this paper follows as:

- The main objective of this study is to integrate machine learning and blockchain in order to improve the traceability system.
- Supporting the product's shelf life for quality evaluation and preventing the time-consuming processes in the supply chain.
- Managing the traceability system by deploying the fuzzy logic platform.
- Light-weight characteristic that is deployed to address the need of the traceability system in the blockchain.
- The proposed food traceability system supplement the modern supply chain environment and generate dependable tracking monitoring and food quality results.
- The decision support in this system follows the fuzzy logic in order to specify the shelf life, rate, and the quality of the product based on the various environments in the perishable food traceability system.
- In order to support the machine learning and monitoring of the environmental IoT sensors, the blockchain is defined to prove the further computational load and light-weight with cloud computing in order to support the machine learning and monitoring of the environmental IoT sensors.

The rest of this paper is divided, as follows: Section 2 presents the literature review of the proposed Blockchain-ML food traceability system. Section 3 presents the system model of the proposed blockchain-based food traceability prediction in a warehouse environment. Section 4 presents the implementation environment of the food traceability blockchain platform. Section 5 presents the system's final result, and we conclude this paper in the conclusion section.

## 2. Literature Review

In supply chain management, Perishable Food Supply Chain (PFSC) is regarded as intricate owing to its environment and the shelf life sensitive presentation [9]. The supply chain has focused on the customer's shared information related to products, the shipment, and monitoring the food saving environment in order to avoid distributing low quality foods and products. This process can minimize the collision disadvantageous of liability, publicity, and recalls. Hence, the food traceability system acts as a critical role in the PFSC system.

### *2.1. Industry 4.0 Key Technology*

Economic growth in most countries is based on the industrial sectors. e.g., the rate of export in Europe is estimated as 75%, and the innovation rate is 80% [10]. Industry 4.0 is for improving companies' efficiency, reliability, and productivity in order to assure the need of customers and gain the companies profits [11]. Industry 4.0 is designed based on four main key technology; the first is called CPS, the integrated communication system. The use of this system is to combine virtual and physical words in various fields. The second one is the internet of things (IoT) technology, which supports human and machine interactions [12–20]. Similarly, it supports the machine-to-machine system and it can monitor, track, control, and identify the location. The third one is the cloud computing technology that focuses on estimating the high performance and low technology in the cloud system, e.g., software and hardware platforms. The advanced big data analysis is the last one, which is applied to pre-process and analyze any type of dataset in order to generate acceptable information and easier decision-making, improving the system's process's efficiency by reducing the costs [21].

### *2.2. Information Sharing in Supply Chains*

Sharing the supply chain information is one of the main roles that presents the experimental information [22–25]. In order to reach the higher improvements, sharing information between partners does not have significant facts. The main core of trust in the supply chain is to focus on partners' cooperation and internal integration. To do this, the manager should know how to identify the information and the best sharing mechanism in order to improve the supply chain's performance. To acquire data, [26–31] develops a hypothetical model that contains four hypotheses, e.g., Information Technology (IT), Information Communication Technology (ICT), Logistic Information System (LIS), and Business Intelligent (BI). A further process, service quality from the service performance, evaluates the market-based quality and resource-based competitive advantages. Based on the processing results, most of the Logistic Service Providers (LSPs) lack implementing some techniques. In order to improve the competition in LSPs, this hypothetical model is defined as a road-map.

### *2.3. State of Art Analysis*

Table 1 presents the comparison of various previously proposed blockchain techniques in the industry and supply chain. After reading different articles, the state-of-art perspective can be comprehended, and some of the related highlights that are related to this article summarized. The table is divided into six categories based on the problem statement, the proposed solution on the mentioned article, the algorithm applied to manage the process, smart contract use in the presented systems architectures, the used blockchain platform, and data transaction.

**Table 1.** Critical analysis of blockchain technology in industry.

| # | Problem Statement | Proposed Solution | Applied Algorithm | Use of Smart Contract | Platform | Transaction Data |
|---|---|---|---|---|---|---|
| 1 | Management system decentralized records [32] | Distributed ledger protocol | PoA | Yes | Ethereum | Medical records |
| 2 | Health records securing system [33] | Dual blockchain structure | PoC | Yes | Ethereum hyperledger fabric | Medical records, Patient records, Practitioners public profile |
| 3 | Data privacy risk reduction [34] | side blocks with smart contract | DNA | Yes | Private blockchain | Medical records |
| 4 | Smart medicine with healthcare [35] | bilinear pairing and public key cryptography technology | PoA | Yes | Private blockchain | Medical records |
| 5 | Pharma supply chain data integrity [36] | IoT and smart contact | PoC PoE | Yes | Ethereum | humidity, temperature data, serial number |
| 6 | Credit based payment optimal loan price [37] | Theory of games | PoA | No | Private blockchain | Energy coin related transactions |
| 7 | localized electricity transaction privacy and security [38] | P2P training model on consortium blockchain | PoA | No | Consortium blockchain | Energy trading data |
| 8 | Information sharing in trust-less network [39] | P2P decentralized blockchain platform | PoA | Yes | Ethereum | Machine type, Event record |
| 9 | Agri-food supply chain trust and reliability [40] | blockchain and IoT | DNA | Yes | Ethereum, Hyperledger | Sensor data |
| 10 | Global education credit platform [41] | European credit transfer and accumulation system | Distributed PoS | No | Hyperledger fabric | Certified grain quality data |
| 11 | UAV compromised detection [42] | UAV pre-registered private key | PoA | Yes | Hyperledger Indy | UAV surveillance detail |
| 12 | Data aggregation privacy preserving [43] | Blockchain and bloom filter, pseudonyms | PoA | No | Private blockchain | Electricity consumption data |
| 13 | Heterogenous vehicular seamless connection [44] | Combination of EV cloud computing and EV edge computing | PoA and PoS | No | Distributed blockchain | coin data |
| 14 | Manufacturing privacy and security enhancement [45] | IoT System bitcoin inspire | PoA | No | Private blockchain | Content request, Address request |

## 3. System Model of the Proposed Blockchain-Based Food Traceability Prediction in Warehouse Environment

This section presents the blockchain machine learning-based food traceability system (BMLFTS) for designing the adaptive blockchain-ML monitoring and food traceability data management system. Similarly, modify the food's shelf life to qualify the food's performance based on the different conditions. Figure 2 shows the proposed BMLFTS framework, which is divided into three modules. First, machine learning techniques are applied in order to predict the estimated expiry date of the product based on the environmental information, like temperature, humidity, oxygen, etc. Following this process, the data that are stored in the cloud database and product life cycle information operate based on blockchain technology. Ultimately, based on the secure and trustworthy dataset, the product shelf life can be modified, and the quality of them is systematically estimated.

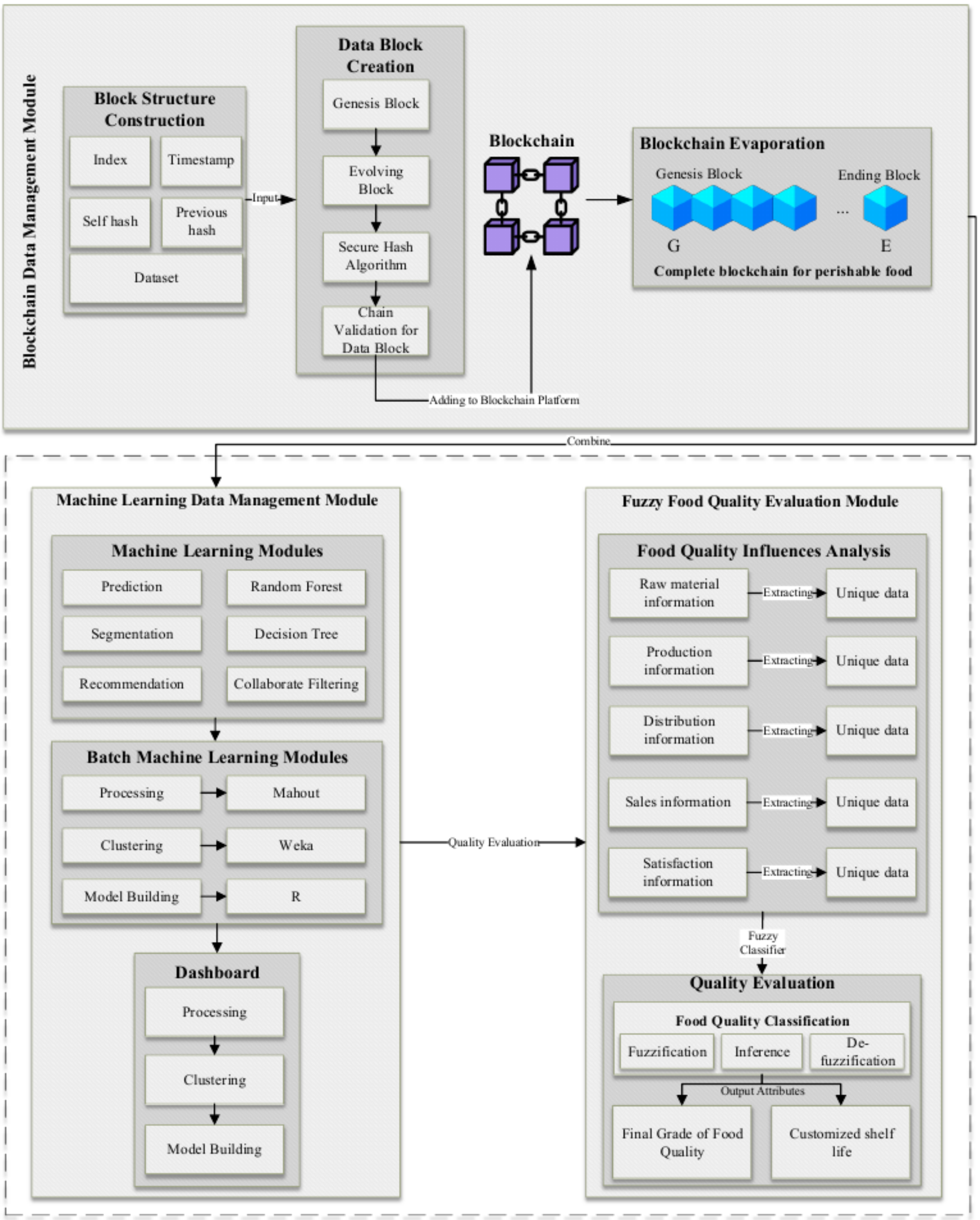



**Figure 2.** Modular framework of the proposed blockchain machine learning-based food traceability system (BMLFTS).

### *3.1. Blockchain, IoT and Machine Learning Conceptual Scenario*

The learning abilities of ML can integrate with blockchain-based applications in order to improve their capability and make them smarter. By applying ML security algorithms, the distributed ledger and time enhancement build a better data sharing route. The proposed Blockchain Machine Learning-based Food Traceability System collects the smart sensors' dataset that is based on IoT technology for environmental monitoring and identifying food through supply-chain operations. The collected data are from devices that are processed using smart applications. Figure 3 shows the process flow of the real-time dataset that was collected from temperature, humidity, etc. sensors. The blockchain plays an integral part in smart applications and, in this case, ML applies data analysis, real-time analysis, and prediction. The used dataset is stored in the blockchain platform. In this case, the rate of errors decreases, e.g., missing values, duplication, noise, etc. The blockchain system focuses on the dataset, and, if the data find any related issues based on the mentioned issues above, ML clears the problem. ML algorithms can be based on special segments instead of the whole dataset in the chain. Such a process can give custom models for various applications, e.g., fraud detection or theft detection identification.

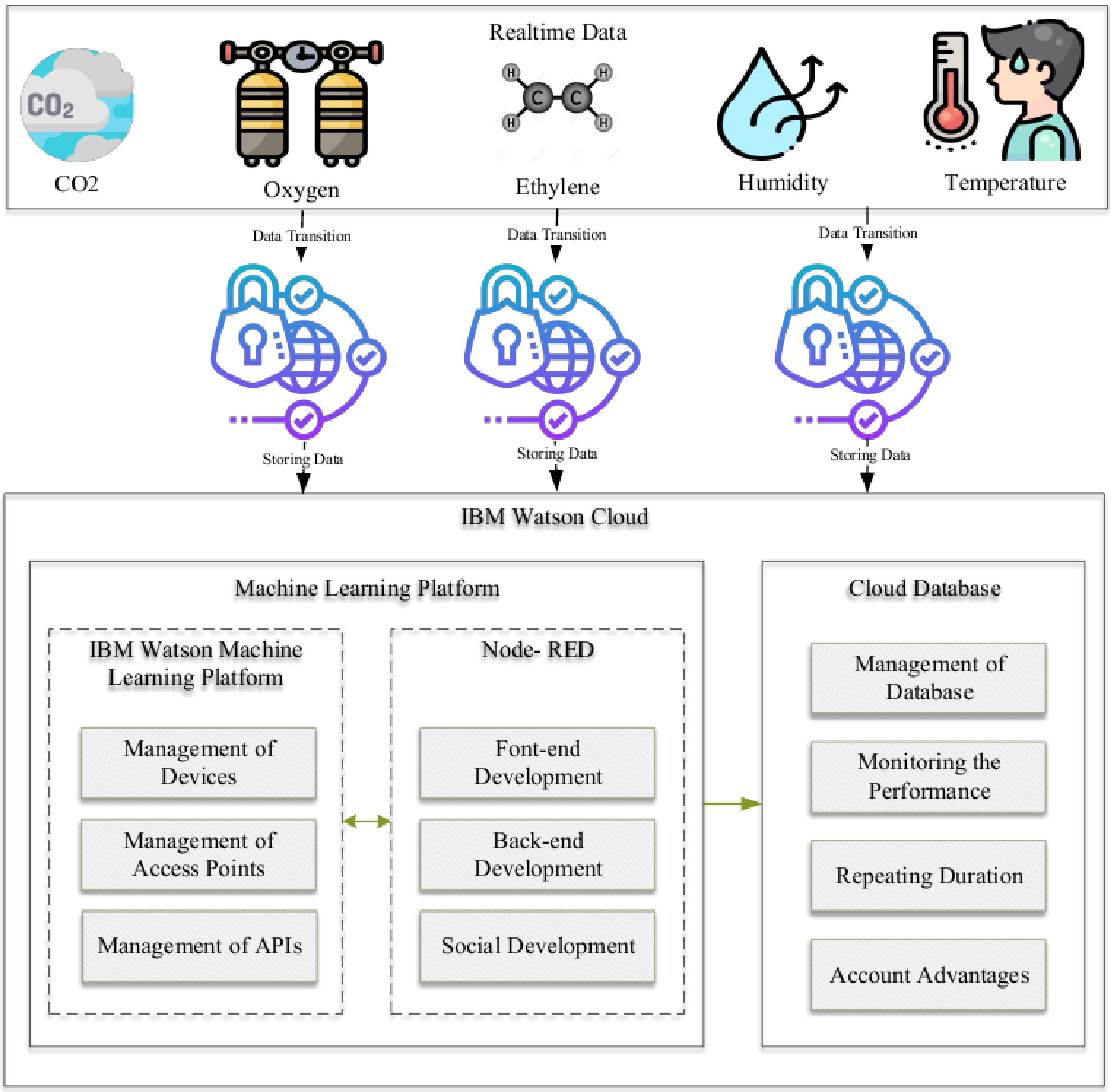



**Figure 3.** Process Flow of the IBM Watson Machine Learning Platform and IBM Cloud.

### 3.2. *Proposed Food Traceability Blockchain Platform Architecture*

When considering blockchain technology deployment, a hybrid approach is applied in order to integrate with machine learning, cloud computing, and blockchain. Moreover, the machine learning combination manipulates the cloud database and the blockchain system's data. Based on the generated product IDs from machine learning, the information that is saved in the cloud database and the light-weight dataset blocks can be formulated. Figure 4 shows the data operation in blockchain to improve the system's flexibility. Based on the consumers' purchases for perishable products from the e-commerce platform, the smart contracts were formulated based on the purchasing records and similarly accessing the product traceability records. Based on the supply chain food cycle, the nodes' start and point are required to evaluate the length of the blockchain. Cryptocurrency has some differences when comparing with blockchain in the data saving process. There is no need to save unnecessary information regarding the dataset. In this case, it will have a negative effect on system efficiency. The blockchain mechanism expands to achieve effective and trustworthy food traceability. A food batch was supplied from the farmer in the first step and processed using the food processors. The batch ID is assigned for products in the genesis block. The supply chain process contains product tracking information, which is stored in the cloud database and blockchain. Container ID and and batch ID are recorded in order to trace the product. Based on the food traceability system's mentioned process in the blockchain platform, the blockchain's stored data are then stored in the cloud database to decrease the memory and storage space.

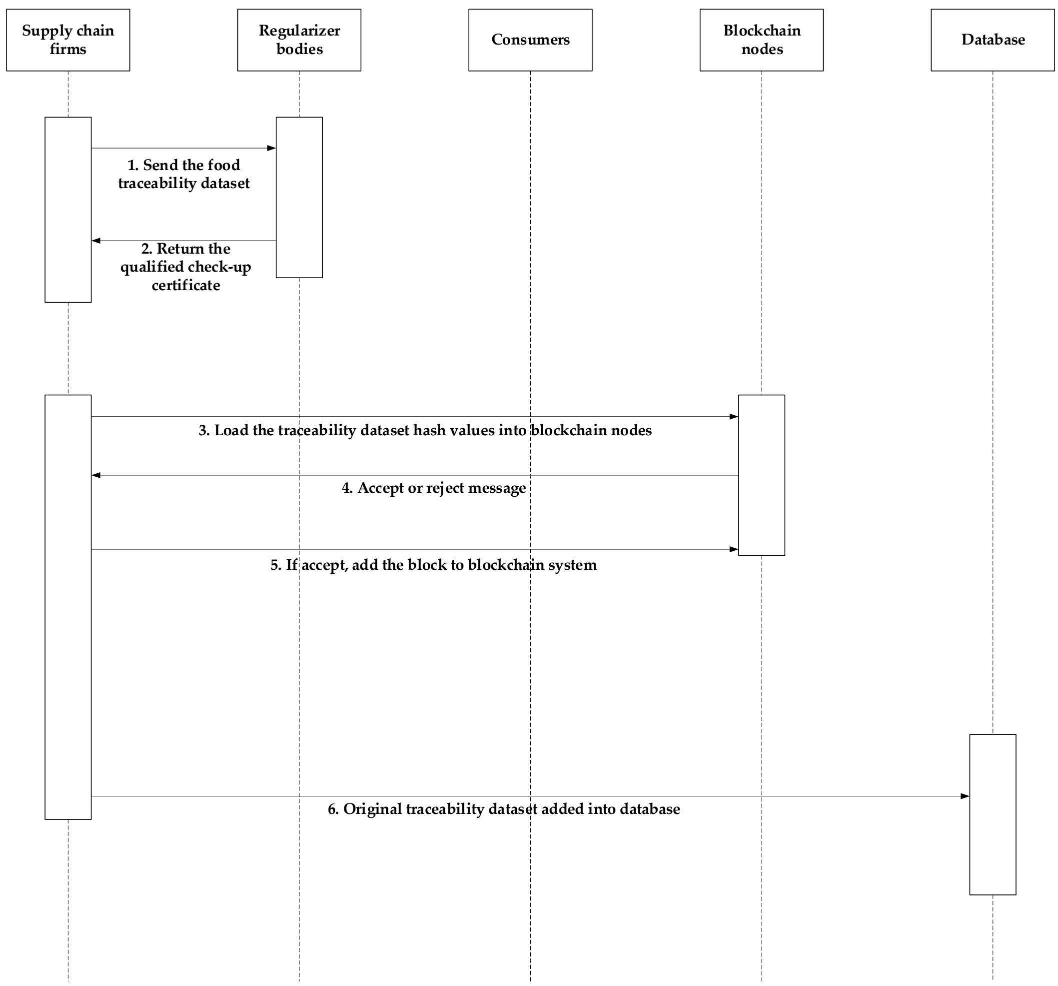



**Figure 4.** Food traceability blockchain platform.

### 3.3. Fuzzy Food Quality Evaluation Module

After data investment from the Blockchain-ML system, the environmental information, activities, and shipment process can apply to set up the PFSC. The food qualification evaluation is processed based on the environmental sensors, where the data were collected from them and managed based on blockchain-ML technology for the pre-processing and structuring dataset. The temperature and humidity measurement were applied based on the corresponding values in order to show the temperature and humidity effects overtime [46]. Moreover, the segregate evaluation of humidity and temperature lacks the reflection in variable temperature and humidity. The main use of these sensors is to evaluate the actual situation of perishable food products. $M_{kt}$ is the measurement of temperature, as defined in Equation (1) where $Temp = Temp_1, Temp_2, ..., Temp_n$ is the fluctuation of temperature and relative humidity $M_H$ is the measurement of humidity where $Humid = Humid_1, Humid_2, ..., Humid_n$ over the transmission time $Time = Time_1, Time_2, ..., Time_n$. Equation (2) is calculating the humidity measurement over the transit time in a certain period. Table 2 presents the notations that are defined in this section.

**Table 2.** Notations used for fuzzy food quality evaluation.

| Notations | Meaning |
|---|---|
| $M_{kt}(Celsius)$ | Temperature measurement |
| $M_H$ | Humidity measurement |
| $A_e$ | Activation energy |
| G | Gas constant |
| S | Moisture sensitivity |
| $Humid_c$ | Relative humidity |
| Time | Transit time |

$$M_{KT} = \frac{A_e}{G[S(Humid_c) - \lambda]}, where\ \lambda = \ln\left(\frac{\sum_{j=1}^{K} Time_j a^{\left[S(Humid_j) - \frac{A_e}{G.Temp_j}\right]}}{\sum_{j=1}^{K} Time_j}\right) \tag{1}$$

$$M_H = \frac{A_e}{S.G.Temp_c} + \frac{\lambda}{S}, where\ \lambda = \ln\left(\frac{\sum_{j=1}^{k} Time_j a^{\left[S(Humid_j) - \frac{A_e}{G.Temp_j}\right]}}{\sum_{j=1}^{k} Time_j}\right) \tag{2}$$

In order to evaluate the food quality, humidity, temperature sensor scores, and transit time were collected to formulate the shelf life $Sh_{life}$, quality rate $R_{qd}$, and quality deteriorate $O_{qd}$. Quality deterioration is evaluated based on the Arrhenius equation. The Fuzzy system's main perspective is to provide an overview of fuzzified input and output, similarly performing better linear and non-linear regression models [47]. This system's whole fuzzy logic platform contains three main components: Fuzzification, de-fuzzification, and inference engine. The first component inputs are pre-defined fuzzified functions, in which the values are transformed into particular values. In the second component, the fuzzy sets transformed into the output of values, which is evaluated in Equations (3) and (4).

$$\delta F_n(V_i) = max[min_x[\delta F_{1b}(Y_1), \delta F_{2b}(Y_2), ..., \delta F_{nb}(Y_n)]] \tag{3}$$

$$\hat{V}_i = \frac{\int Q_i.V_i.\delta F_n(V_i)dV}{\int Q_i.\delta F_n(V_i)dV} \tag{4}$$

Here, $\delta$ is defined as a belonging parameter in a fuzzy system .$Q$ is defined as a weight of values. $V$ is defined as an output of fuzzy functions. The considering rule is defined as $b$. $Y$ is the converted parameter to corresponding values.

### 3.4. Fuzzy Inference System Structure

Based on traditional practices, the shelf life of the food products captures the environmental conditions and transit time based on food operatives and buyers' supply chain operations. However, this process cannot affect the real condition for the spoiling and deterioration of food shelf life. To reach a good quality managment, a fuzzy logic system defined shelf life and quality decay of perishable food products. Table 3 presents the fuzzy classes of membership for input and output. Three options show the trimf (triangular membership function), and four options show the trapmf (trapezoid membership function).

**Table 3.** Fuzzy logic membership function on food traceability system.

| Input | Formula | Class of Fuzzy | Membership Function | Type |
|---|---|---|---|---|
| Temperature | $M_{kt}$ (Celsius) | High | (20,30,55) | trimf |
| | | Medium | (5,15,30,40) | trapmf |
| | | Low | (0,5,15) | trimf |
| Humidity | $M_H$ | High | (65,75,105) | trimf |
| | | Medium | (35,45,65,75) | tapmf |
| | | Low | (0,35,45) | trimf |
| Transit Time | $V_i$ | High | (55,105,155) | trimf |
| | | Medium | (35,55,105) | trimf |
| Output | | | | |
| Shelf life | $Sh_{life}$ | Increase | (0,55,105) | trimf |
| | | No effect | (–55,0,55) | trimf |
| | | Decrease | (–100,–55,0) | trimf |
| Quality Decay Rate | $R_{qd}$ | Medium | (0.03, 0.05, 0.07, 0.09) | trapmf |
| | | Low | (0,0.03, 0.05) | trimf |
| Quality Decay Order | $O_{qd}$ | First order | (0,1,2) | trimf |
| | | Second order | (1,2,2) | trimf |
| | | Zero order | (0,0,1) | trimf |

### 3.5. Quantitative Quality Measurement

In order to measure the quality control of scientific application, there are various ways defined as:

- Maintainability: this attribute executes the software changes, e.g., improving the software, correcting the problems, and achieving the acceptable environment.
- Portability: this attribute can transfer the software to various environments.
- Reliability: this attribute improves performance based on stable conditions in a special period.

The main reason for applying these attributes is to control the dataset and evaluate the output based on the time and sources limitation. The level of representation of attributes evaluated based on $QC = C_1, C_2, ..., C_m$. Attributes were presented as $C$ and belonged to a set of defined attributes above. This process shows the importance of the measured attributes for the quality of the proposed system.

The following Equations presents the quality control evaluation on the proposed system. The average size for system transaction is evaluated in Equation (5):

$$Size.of.block/Overal.Transaction \tag{5}$$

The total number of blocks and transactions per block evaluated in Equations (6) and (7):

$$C_m = \frac{L}{C_L} \tag{6}$$

$$C_{L_y} = \frac{L_{y.day}}{C_m} \tag{7}$$

$C_m$ defines the number of blocks, $L$ presents the total time, and $C_L$ presents block time. $C_{L_y}$ shows the total transaction per block in system. $L_{y.day}$ shows the number of daily transactions of a system based on Equation (8):

$$L_{y.day} = \frac{L_y}{second} \times L \tag{8}$$

### *3.6. Smart Contract in the Proposed Food Traceability Blockchain Platform*

A smart contract is a blockchain self-enforcing agreement in the form of a computer code developed by Nick Szabo in 1994 [48]. The code contains the various specified rules, in which the smart contract participants agree on these rules. For efficient system managing, the smart contract supplies tokenized assets to the available parties' rights. The smart contract in Ethereum is designed based on stack-based low-level bytecode language, which is executed by Ethereum virtual machine (EVM), and it is named EVM code. The defined code is congested in the unique binary form in blockchain Ethereum. The smart contract can manage the high-level languages, e.g., Solidity [49] and EVM compiled code. A virtual machine is the main core of Ethereum that can perform the complexity based on an arbitrary algorithm. Based on the increasing technology in computer science, Ethereum is known as Turing-complete. A wide variety of contracts can be created based on developers' decisions while using DApps on Ethereum Virtual Machine on various programming languages, e.g., Python, Java, etc. Various operation logics can handle in a smart contract, and the capabilities of Ethereum can make the blockchain a more scalable and extensive development platform.

## 4. Implementation Environment of the Proposed Food Traceability Blockchain Platform

Figure 5 presents the implementation environment of the proposed BMLFTS, which is defined into four processes. Machine learning techniques are applied for predicting the perishable food quality and reducing the costs. Additionally, the whole environmental monitoring is designed to cover the supply chain. For tracking and tracing the product through the supply chain, the combination of Blockchain-ML was applied in the system. The key point of this system is light-weight blockchain technology. A blockchain-ML food traceability process can be designed in order to monitor the effects of the perishable food supply chain.

### *4.1. Smart Contract Modeling of the Case Study*

Three smart contracts were designed in the proposed system in order to extract the food traceability information. The mentioned three smart contracts are named Product Registration Contract (PRC), Batch Additional Contract (BAC), and Transaction Update Contract (TUC). The BAC contract addresses are saved in the PRC contract and, similarly, the TUC contract addresses are saved in the BAC contract. The reason for this action is to link these three contracts to each other. For easier explanation, searching for the specific name contains the related information and raw data simultaneously. The BAC contract addresses allocated into PRC contract to add the product batch information. In order to update the transfer information of the product, the BAC contract is assigned to the TUC contract. This means that each product contains a batch list, and each batch list contains the product transfer information. Based on this information, the consumer can track the purchased product easily. Each contract specific functions is described below:

- Product Registration Contract (PRC): the PRC contract was established by the system manager to come up with product registration function "register ()" in order to save the complete product information. The registered information contains the product name, specific code for each product, and the customer's name, which orders the product. Table 4 is an example of the mentioned information that is stored in the PRC contract. After the product registration, it will post into the BAC contract to save the product customer account information. The BAC contracts design a production batch based on the customer information and they are sure not to save the batches' repeated information.
- Batch Addition Contract (BAC): the BAC contract was established by the product customer to register the product with the "addBatch ()" function in order to save the batch information. The batch information is designed to contract a batch for each product, including the batch number and the products' raw information mentioned above. Table 5 presents an example of the BAC contract for a product. The product transaction updating in the TUC contract shows the product nodes in the supply chain in which the product entities go through the moving process.
- Transaction Update Contract (TUC): the TUC contract was designed to update the product transaction information, which defines the function of "updateTr" for the product batch. This process is updating the information based on the time that the sender is sending the product and how the customer receives the product. First, the transaction from the sender is built in order to make the receipt for the product and add the product transaction information. In this case, the product code and batch number are attached. Suppose that this information is not available in the previous transaction that is attached to the system. The second is when the transaction launch from the sender and the transaction information add to the transaction records. This process contains the hash of the current transaction. Table 6 is an example of the TUC contract to show the transaction list with the updates of the well-packed products in the blockchain and the previous valid transactions hash records. This process makes sure that the added transactions in the blockchain are reliable and legal, and similarly prevent any interruption in the product traceability process.

**Table 4.** Example of Product Registration Contract (PRC) contract product information.

| # | Product Code | Product Name | Product Owner | Raw Material | Timestamp | BAC Address |
|---|---|---|---|---|---|---|
| 1 | 210846924 | eggplant | 0x08...g0w5 | / | 1451054044 | 0xcdf0...e5d88 |
| 2 | 276547524 | carrot | 0x45d...e345 | / | 1451054105 | 0x5706...8301d |
| 3 | 7039501445899 | cucumber | 0x91b...2342 | 210845924 | 1451054165 | 0xb022...0bd6b |
| 4 | 294224218 | apple | 0x45q...0f3s | / | 151054300 | 0xb256...0f7e5 |
| ... | ... | ... | ... | ... | ... | ... |

**Table 5.** Example of Batch Addition Contract (BAC) contract product code for the 7039501445899 in Table 4.

| # | Batch Code | Raw Material with Batch Code | Batch Manager | Timestamp | TUC Address |
|---|---|---|---|---|---|
| 1 | 202018232716 | 101846924(202017392137) | 0x70b...11124 | 1673733835 | 0xc357...2ffcg |
| 2 | 202018242317 | 101846924(202017312647) | 0x49d...0e3b | 1673833867 | 0xd2c3...e8160 |
| 3 | 202018242927 | 101846924(202017412649) | 0x00g...d1d2 | 1673933890 | 0x9887...24ee5 |
| 4 | 202018252839 | 101846924(202017112649) | 0xbb5...ef74 | 1673033927 | 0x5005...de880 |
| ... | ... | ... | ... | ... | ... |

**Table 6.** Example of Transaction Update Contract (TUC) contract product transaction for batch number 202018232716 in Table 5.

| # | TrHash | Sending | Receiving | PreviousTr | Timestamp |
|---|---|---|---|---|---|
| 1 | 0xb7147...9g6829d | 0x2b0...d90c | 0xeef...09b0 | 7039501445899(202018232716) | 1674734858 |
| 2 | 0x0bef5...3203gf | 0xeef...19b1 | 0x3cc...1366 | 0xb7147...9g6829d | 1674934948 |
| 3 | 0x9d697...f510b6 | 0x3cc...0166 | 0xdb8...d755 | 0x0bef5...3204gh | 1674734164 |
| 4 | 0xegb0c...eg3578 | 0xdb8...d755 | 0xbb5...ef74 | 0x7d697... | 1674735178 |
| ... | ... | ... | ... | ... | ... |

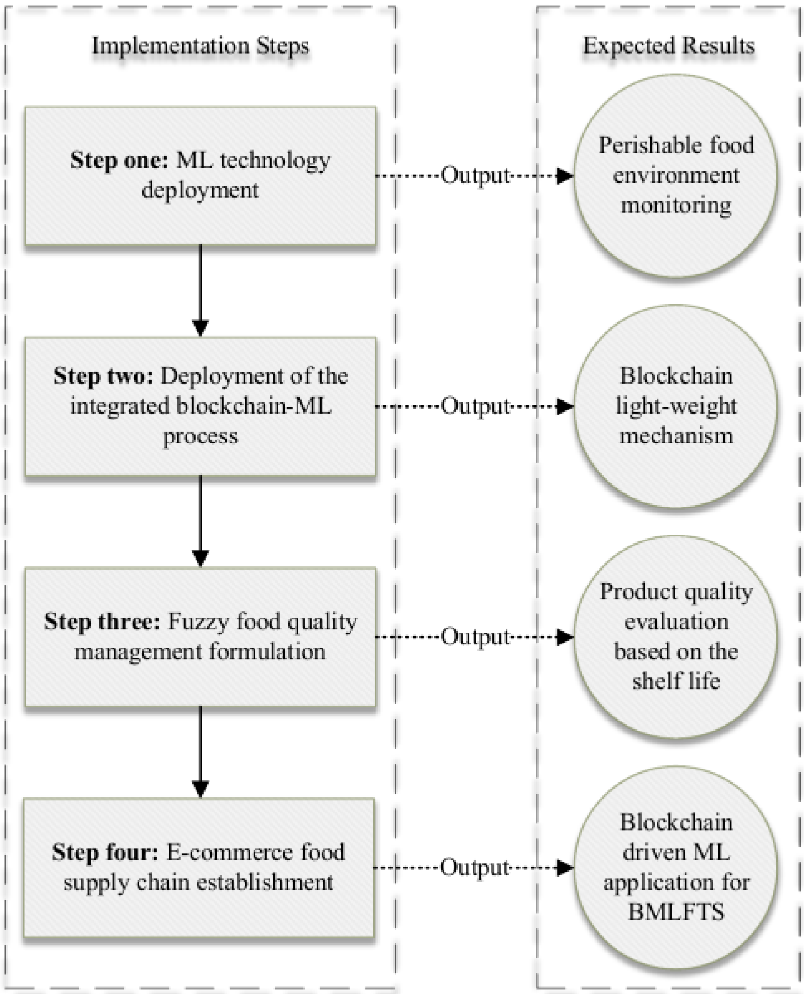



**Figure 5.** Implementation process of the BMLFTS in perishable food supply chain (PFSC).

### *4.2. Execution Procedure of the Case Study*

In order to confirm the proposed BMLFTS performance, the case study operates in a retail e-commerce company. The whole implementation is presented in detail based on the need of the company.

- Background of the company and problems: the MATRO Store in South Korea is the mentioned company, which is one of the famous 24 h marts, providing the perishable food product. It enthusiastically entered into the perishable food products business, which contains the e-commerce platform, food supplier appropriate sources, process the implementation, and multi-temperature delivery for last miles. The main provided aspects can be mentioned as business-to-customer (B2C) and customer-to-customer (C2C), which is a domestic food supply. In the generic platform of e-commerce, it is possible for the shipment detail information to provide to them. Customers are curious to know the shipment's details regarding the supply chain covering information on the food quality and management environment, regardless of managing the e-commerce business of perishable food. Furthermore, some solutions provided while tracking the food quality to save time and reduce the costs. This is especially true in regards to covering the intentions that are related to shelf life. To sum up the contents, customers are interested in knowing the quality of the delivered product in the perishable food supply chain, which is the main aspect of the company for improving the company's performance and image for the future. On the opposite side, if the customer receives the perishable food product with low quality and delivery, then it will damage the perishable food e-commerce business. Therefore, the company needs to provide a trustable food traceability system with an effective process and real-time monitoring.

- BMLFTS Road-map Implementation: the proposed (BMLFTS) is for implementing the complete food traceability system based on the quality of food and the management system into recent technology.

### *4.3. Proposed Machine Learning Based Predictive Analysis*

Most of the machine learning techniques are used for evaluating the prediction of the system. The correct and valid prediction model is an effective step in decision making and analysis. The prediction process in the proposed system is standing on the Bayesian regression and random forest algorithms. This allows for the evaluation of the prediction in the wide range of features without overfitting. Block size, total products, transaction records, transit time, shelf life, and environmental sensors are the main features that are used for prediction. Data normalization is processed using linear and log scaling techniques. The correlation matrix for the defined features reports the main network trends. ML's main goal contains the prediction, detection, monitoring, response, and prevention steps. To do this, there are some layers that contain user, process, endpoint, and application. Similarly, counter measuring contains real-time and analytic steps, and, finally, the smart app's process contains customer service, manufacturing product, trading data, utilities & energies, and personalized devices.

## 5. Experimental Result of the Food Traceability Blockchain Platform

The Blockchain-ML technologies are useful for the food traceability system in terms of PFSC business based on the BMLFTS implementation. The light-weight characteristic of blockchain presented in order to apply the decision-making process to evaluate the shelf life based on the collected dataset. The blockchain advantages have an improvement in system reliability, the efficiency of traceability, and the majority of mechanism which has a practical effect in the e-commerce business of perishable food system. The proposed system's advantages summarized, as follows: (1) security of the food traceability system in the distributed supply chain. (2) The light-weight design of blockchain for reducing the hardware capability and computational load. (3) Food quality evaluation based on the product shelf life. Following the BMLFTS provides the business value of Blockchain-ML in the management of the supply chain. The following section contains the prediction result of the food traceability system, comparison, and significance, and the BMLFTS challenges in the food traceability system.

### *5.1. Performance Evaluation of the Food Traceability System*

We have used an open-source dataset in order to evaluate the performance of the BMLFTS model. The algorithm's majority opinion reflects on the transit time, stakeholder analysis, and shipment in the supply chain. Therefore, the main mechanism of blockchain can apply in PFSC for food traceability. Figure 6 considers the supply chain transit time, which not reliable for the conjecture of the stakeholders' value or conditions. Thus, the shipment volume and stakeholder analysis are integrated with transit time for establishing the measurement weight.

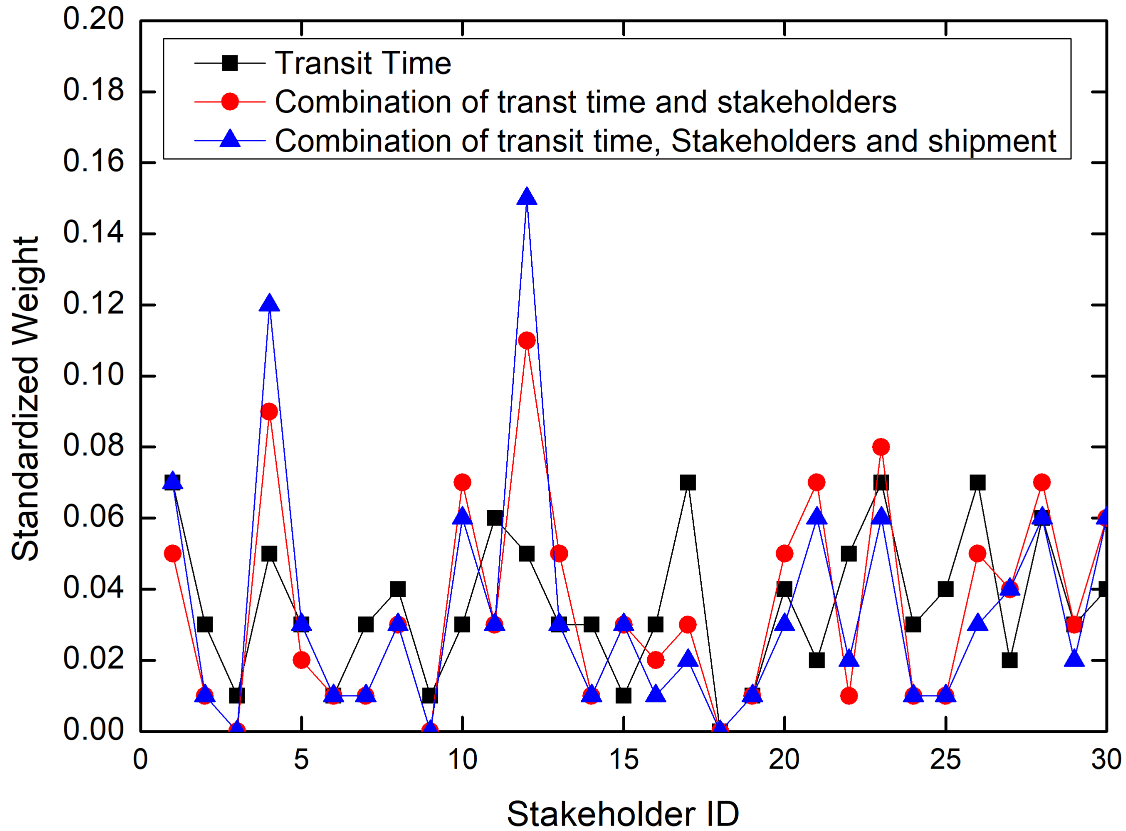



**Figure 6.** Network Performance Analysis.

Figure 7 represents the various rate of material correlates with costs. If the rate of material increases, in that case, the cost of $register()$ and $addbatch()$ increase according to process and, if there are no changes in the operation, then the $updateTr()$ remains the same. The meaning of this process relates totally to the cost, which, for each, changes the system updates.

Figure 8 shows the uploaded time of information in the system that is based on the request uploads. The system request frequency is 100 times to 900 times per second. The time of the uploaded information is from seven seconds to 47 seconds. The figure shows how the process increases based on upload records. The pick of the system is between 700 to 900. The main reason for this matter is the blockchain system restrictions, in which a single block has the limitation of transaction.

Figure 9 shows the response time of request determined on the amount of chain data and the traceability request. It represents the information response time, which is growing between 2 ms and 5 ms and, similarly, the chain data are increasing from 1 G to 9 G.

### *5.2. Comparison and Significance*

The proposed food traceability system is compared with other approaches. Table 7 illustrates the comparison results. The specific analysis is explained, as follows.

- Traceability: the schemes also are part of the traceability system because of the traceability system comparison.
- Decentralization Degree: the proposed method uses blockchain technology in the food traceability system of the supply chain in order to clear the private changes of data due to investment. Similarly, consumers are able to join the system for supporting the blockchain public and clear data. In comparison with the previous approaches schemes, [50] has been specified in the partial decentralized scheme because the consumer is an off-line chain contributor and cannot access the copy of the supply chain ledger. Because of these reasons, the decentralization degree is relatively low.

- Scalability of the system: for the proposed framework in the development environment, the extension points are designed to add different functions easily, e.g., the reviews' functionality.

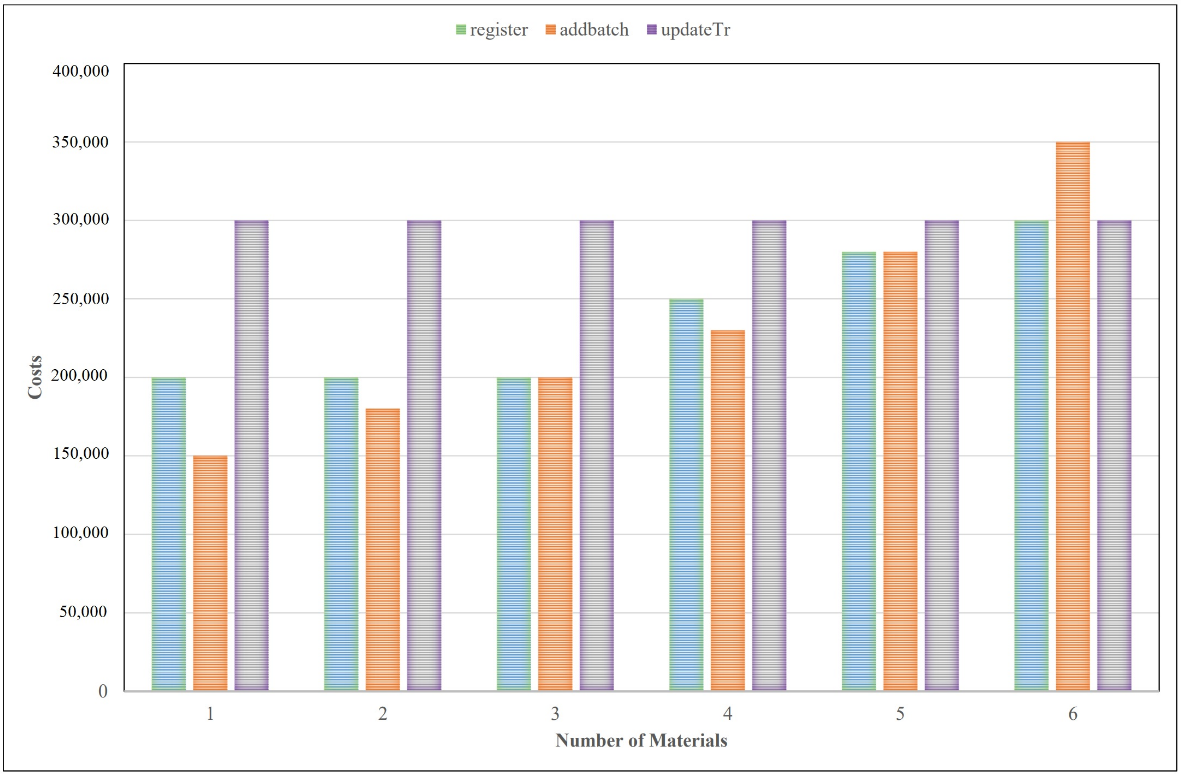



**Figure 7.** Smart contract operation costs.

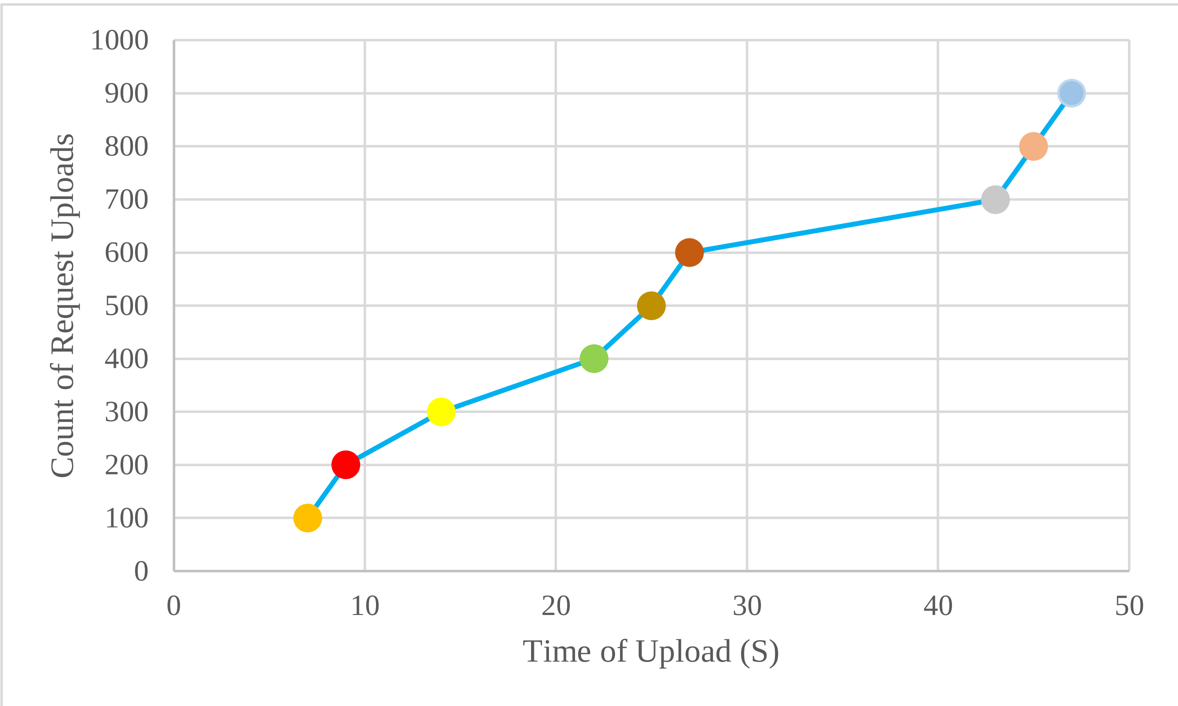



**Figure 8.** Relationship between the uploaded request and uploaded time.

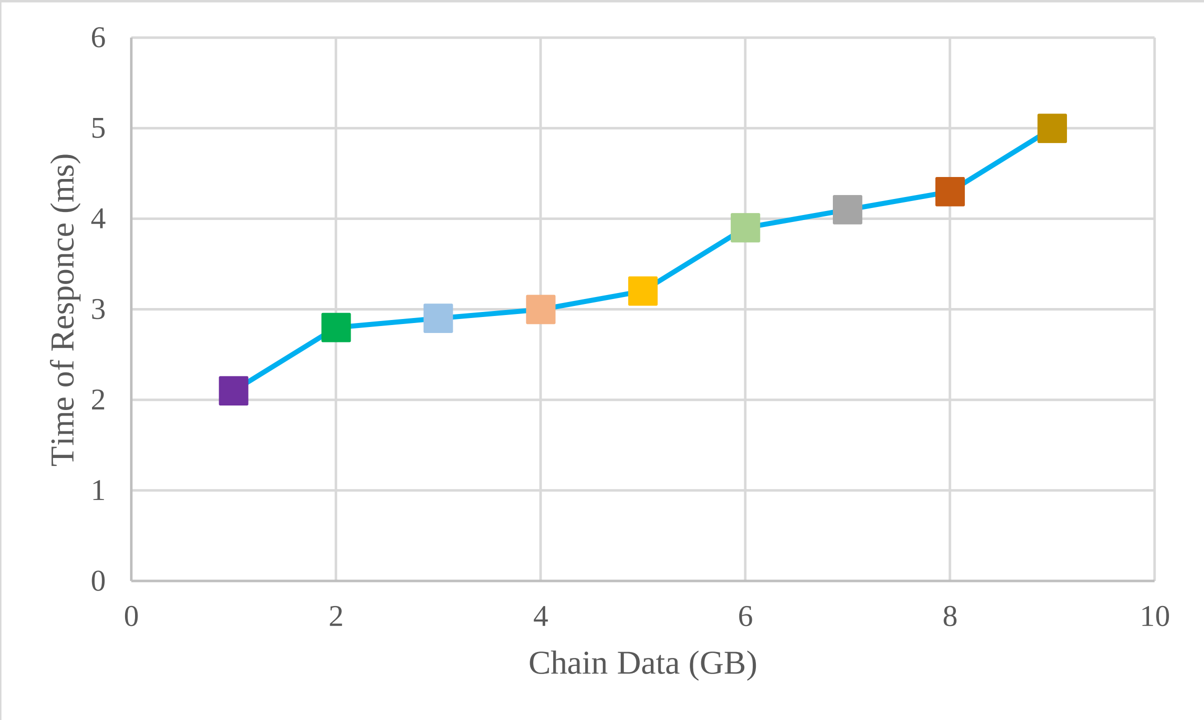



**Figure 9.** Relationship between the chain data and response time.

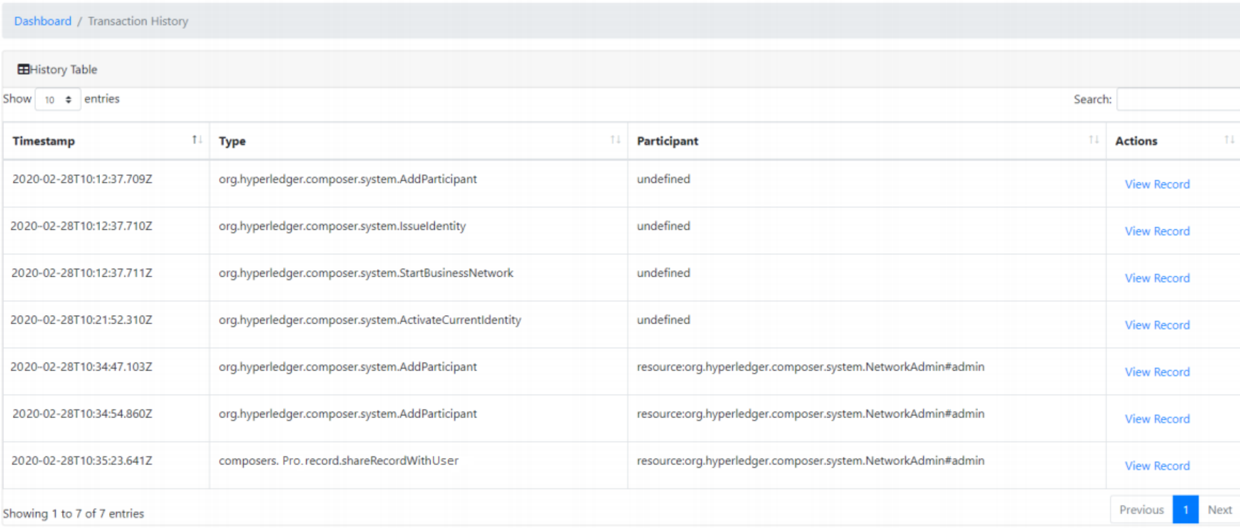
**Table 7.** Various Schemes Comparison.

| # | 1 [51] | 2 [50] | 3 [52] | 4 [53] | Proposed System |
|---|---|---|---|---|---|
| Traceability | Yes | Yes | No | Yes | Yes |
| Decentralization Degree | High | Low | High | High | High |
| Scalability | No | No | Yes | No | Yes |

Figure 10 shows the user interface in the BMLFTS. The transaction displays the web to blockchain web interface log file. The attributes of the log file are defined as the timestamp, type, and participants. The timestamp shows the detailed time of transactions. The type presents, type of performed transactions, and the participants present the user information who did the transactions. Figure 11 shows the system response time that is based on the various number of users. The simulation time is 100 ms. The response time also increases based on the increasing number of users. The users define three groups. The two groups have almost the same time, but the system performance also increases by increasing users' number. Figures 11–13 show the key performance indicator (KPI) of the traceability system. The proposed system's efficiency was tested with various computational time and iterations that are based on the associated IDs and traceability information in order to keep the system's security. In this procedure, the delay time and the number of iterations are defined for monitoring the loop's progress. The number of iterations and execution time show the traceability system's efficiency that is based on the associated IDs.

### *5.3. Challenges of Applying BMLFTS in Food Traceability System*

Based on the proposed system, there are two main challenges in the food traceability process. First, human factors are supposed for use in the implementation. The reason is the blockchain feature with it has the ability to keep data out of any changes or retouching data, but it has the possibility that workers in the supply chain provide fake information or incorrect data for food traceability. Hence, there is a need for measurement in the food traceability system in order to strengthen the practicality of the BMLFTC. The success in blockchain technology is based on an accurate dataset. Second, supply chain stakeholders' honesty accepts the proposed system. For a detailed explanation, the food traceability system supposes to receive the data from all of the supply chain procedures. In this case, the whole powerful party of the supply chain must be identified in ordr to accept the system. Apart from that, the system acceptance rate becomes low, and the supply chain-related information might break.


Dashboard / Transaction History

History Table

Show 10 entries Search:

| Timestamp | Type | Participant | Actions |
|---|---|---|---|
| 2020-02-28T10:12:37.709Z | org.hyperledger.composer.system.AddParticipant | undefined | View Record |
| 2020-02-28T10:12:37.710Z | org.hyperledger.composer.system.IssueIdentity | undefined | View Record |
| 2020-02-28T10:12:37.711Z | org.hyperledger.composer.system.StartBusinessNetwork | undefined | View Record |
| 2020-02-28T10:21:52.310Z | org.hyperledger.composer.system.ActivateCurrentIdentity | undefined | View Record |
| 2020-02-28T10:34:47.103Z | org.hyperledger.composer.system.AddParticipant | resource:org.hyperledger.composer.system.NetworkAdmin#admin | View Record |
| 2020-02-28T10:34:54.860Z | org.hyperledger.composer.system.AddParticipant | resource:org.hyperledger.composer.system.NetworkAdmin#admin | View Record |
| 2020-02-28T10:35:23.641Z | composers. Pro.record.shareRecordWithUser | resource:org.hyperledger.composer.system.NetworkAdmin#admin | View Record |

Showing 1 to 7 of 7 entries Previous 1 Next

**Figure 10.** Transaction history of the food traceability.

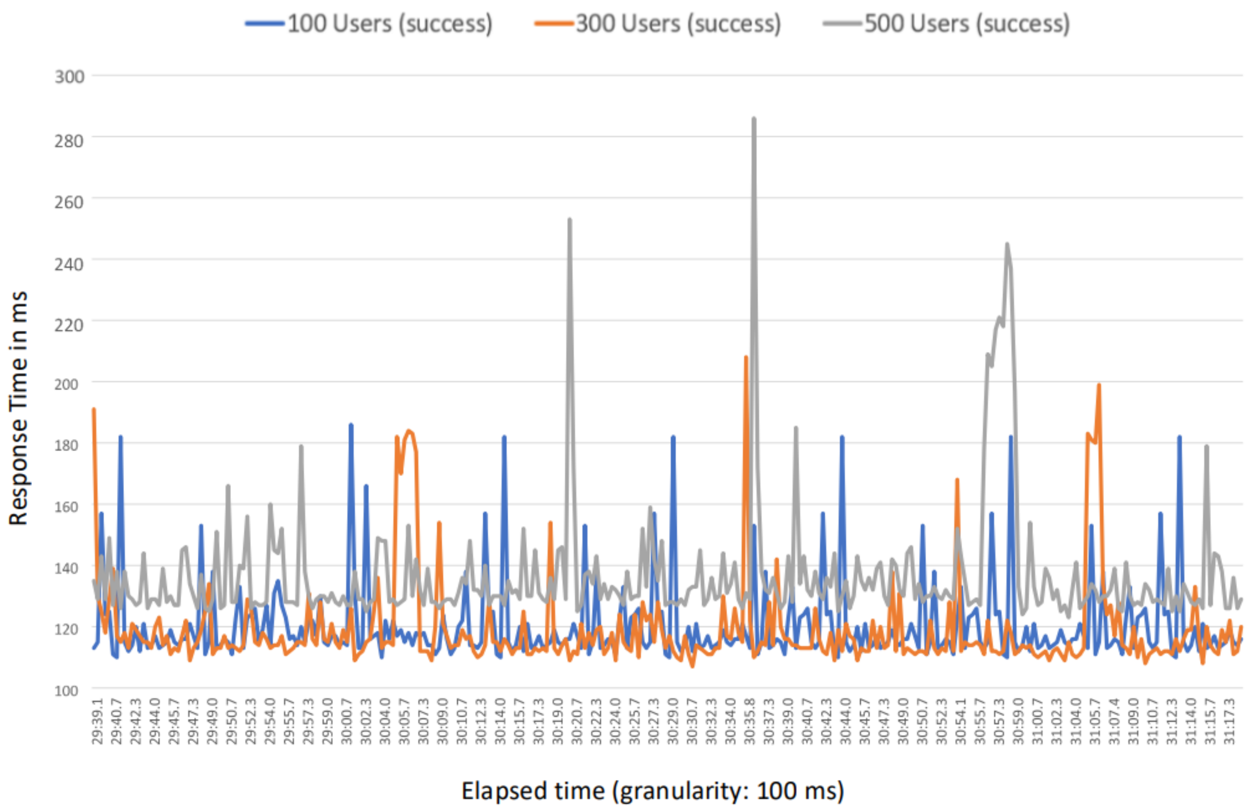



**Figure 11.** Response time for the various group of users.

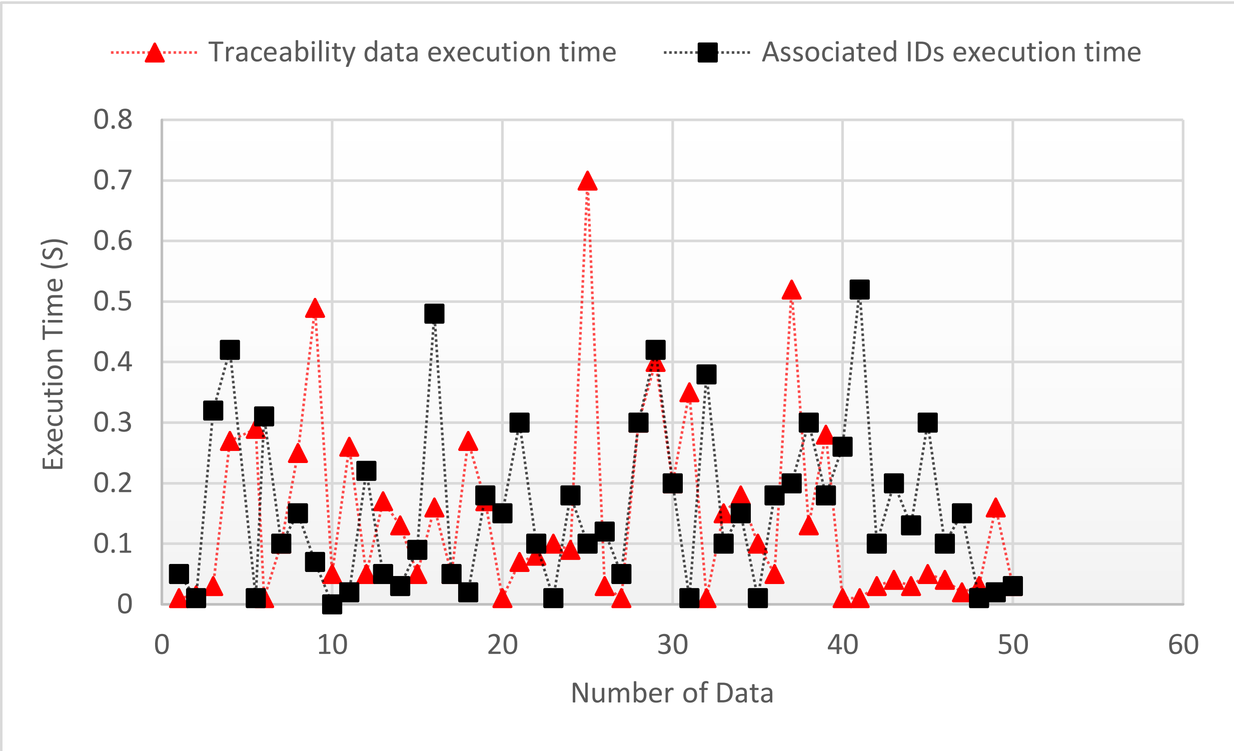



**Figure 12.** Key performance results of the traceability system.

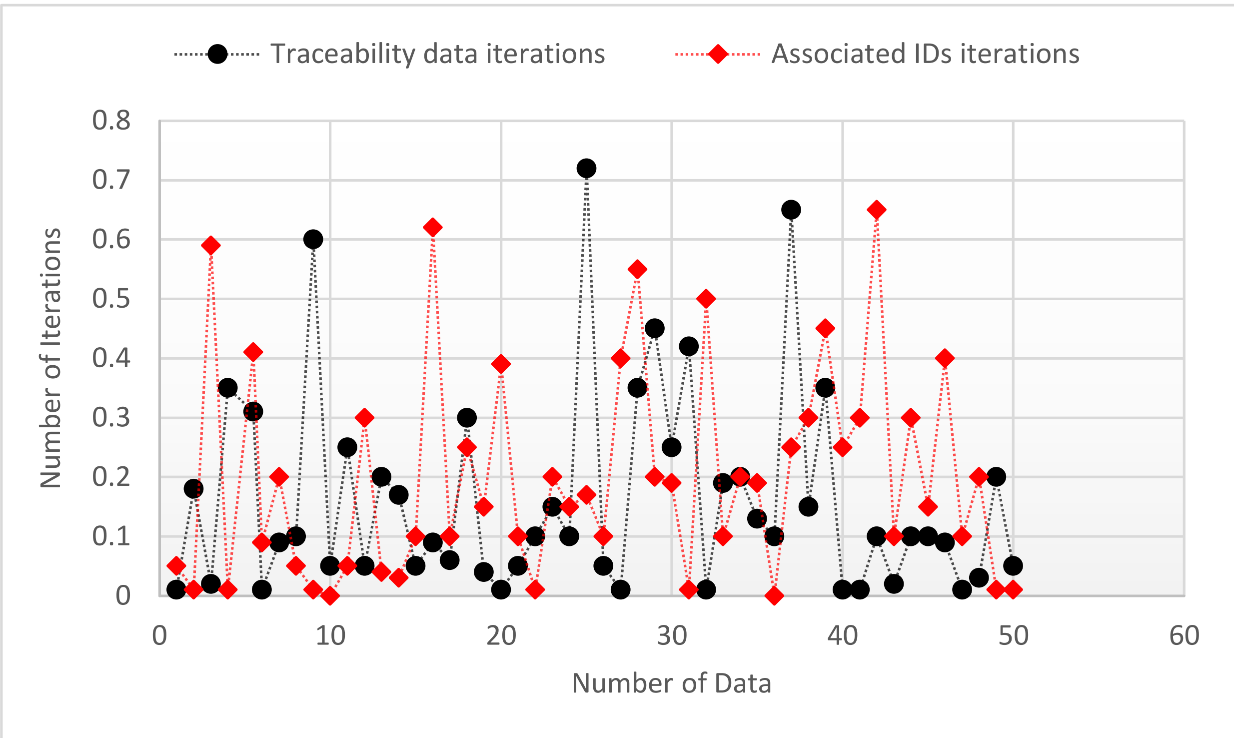



**Figure 13.** Key performance of number of the iterations.

## 6. Conclusions

Food traceability is one of the important and decisive processes in PFSC, which shows the food's total life cycle information. Moreover, customers and supply chain stakeholders follow this process in order to have the best decision. Based on the quick extension of the e-commerce business, perishable food e-commerce becomes a famous option in online platforms as compared with wet markets. There is no information regarding the product, which makes the customer sure as to whether the item is fresh. From another perspective, food perishable is a sensitive and considerable area, due to food discrepancy and deterioration. Therefore, there is a need for a food traceability system to have all of the information related to product data from manufacturing to distribution. In this paper, all of the issues mentioned above are addressed by applying the Blockchain-ML mechanism and fuzzy food quality evaluation based on the food traceability system's supply chain. The ML techniques were applied in order to achieve user convenience, and all of the processed datasets were managed into the cloud database to obtain the time stamp and traceability ID in the blockchain system. In order to achieve the supply chain's primary meaning in the proposed system, the supply chain stakeholders and transit time are evaluated in order to achieve the shipment volume. The applied dataset is used to measure the shelf life and quality of the product, which is the positive aspect of the process for customers to trace the product's purchased food and quality status. The limitation of the proposed system is based on the food traceability scenario, which is the use of other supply chain applications. For further study and improving the proposed method, two main aspects are mentioned: the proposed system should not be limited to food traceability and more analysis aspects can be added, e.g., managing the risks and e-commerce transactions. Similarly, information flows, such as risk, material, and value, can be covered by an integrated approach, in order to create a more secure and reliable supply chain.

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