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Innovative Blockchain-Based Approach for Sustainable and Credible Environment in Food Trade: A Case Study in Shandong Province, China

Dianhui Mao [1,2], Zhihao Hao [1,*], Fan Wang [1] and Haisheng Li [1,2]

1 Beijing Key Laboratory of Big Data Technology for Food Safety, School of Computer and Information Engineering, Beijing Technology and Business University, Beijing 100048, China; maodh@th.btbu.edu.cn (D.M.); wfan0601@163.com (F.W.); lihsh@th.btbu.edu.cn (H.L.)

2 National Engineering Laboratory For Agri-product Quality Traceability, Beijing 100097, China

* Correspondence: hao_zhihao@126.com; Tel.: +86-152-1059-6256

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Abstract: Agri-food trade has a profound impact on social stability and sustainable economic development. However, there are several technological problems in current agricultural product transactions. For example, it is almost impossible to improve the efficiency of transactions and maintain market stability. This paper designs a novel Food Trading System with COnsortium blockchaiN (FTSCON) to eliminate information asymmetry in the food trade, in order to establish a sustainable and credible trading environment, the system uses consortium blockchain technology to meet the challenge of different authentications and permissions for different roles in food trade. Meanwhile, we have used the online double auction mechanism to eliminate competition. We also have designed a improved Practical Byzantine Fault Tolerance (iPBFT) algorithm to improve efficiency. In addition, a case study based on a series of data from Shandong Province, China indicate that the FTSCON can achieve profit improvement of merchants. Therefore, the proposed system proved to have high commercial value.

Keywords: sustainable agri-food trade; consortium blockchain; combination strategy; consensus process

1. Introduction

Agri-food trade is not only related to farmers' income and consumer burden, but is also central to civic life and social stability. It is thus an area of high social and political sensitivity. There are many stakeholders in agri-food trade: farmers, processors, traders, wholesalers, retailers and consumers. They face uncertainty and demand high-quality and safe food products, along with as much information as possible [1]. Therefore, there may be an information asymmetry problem. Asymmetric information occurs when parties involved in an economic transaction are not equally informed and prevents the first-best allocation of resources. Information asymmetry may cause a series of problems, such as market failure [2]. At present, many countries are trying to reduce market failures and create a fairer trading environment in the agriculture and food industry. For instance, on 12 April 2018, the European Commission acted to ban the damaging trade practices caused by information asymmetry in agri-food trade to ensure fair treatment for small- and medium-sized food and farming businesses [3]. These include late payments for perishable food products [4], last-minute order cancellations, unilateral or retroactive changes to contracts [5] and so on [6]. These problems not only harm the stability of the food market, but also lower the efficiency of transactions. In addition, the complexity of the transaction process, high transaction costs and long transaction times can lead to inefficient transactions. Therefore, it is necessary to find solutions that can protect fairness and improve efficiency in food transactions.

At present, a majority of modern agri-food trade infrastructures are centralised and implicate the involvement of a trusted third party [7], which handles accounts, processes payments and provides security. Commerce relies on trust and verified identity, with a cryptographic protocol module embedded in the system to ensure the credibility of the data and other security requirements [8]. Generally, the centralised trading system still has many drawbacks, such as a crisis of trust caused by information asymmetry and weaknesses allowing information to be tampered with easily. This becomes the death knell for merchants in the food market. Information asymmetry exists widely and may cause many problems. For example, it may affect both the immediate market reaction to earnings announcements and the post-earnings announcement drift [9]. The theoretical literature suggests that disclosure improves liquidity by reducing information asymmetry on the one hand and increasing transaction volumes on the other [10]. However, the problem of information asymmetry is not always left to the entities involved. Simplice et al., for example, use information and communication technology (ICT) to reduce information asymmetry [11]. However, it remains a hard-to-solve problem. At present, decentralisation can solve these problems perfectly by providing credible transactions in an environment of trade mistrust. Hence, there is extensive research related to trading mechanisms to improve the quality of service, including a trading system using blockchain technology in the food sector. Such a system now attracts the interest of experts in several industries [12].

Blockchain technology can be put to use as a mechanism to safeguard trading. It has attracted the interest of stakeholders across a wide span of industries: finance [13] healthcare [14,15], utilities [16], real estate [17] and the public sector [18]. Recently, it has been introduced for food trading [19]. The reason for this explosion of interest is that, with a blockchain in place, applications that could previously run only through a trusted intermediary can now operate in a decentralised fashion, without the need for a central authority, and achieve the same functionality with the same amount of certainty. This was simply not possible before. The blockchain is a P2P distributed ledger technology that enables food trading to be executed in decentralised, transparent and secure market environments.

Motivated by these developments, in this paper, we exploit the consortium blockchain technology to develop a secure food trading system. The consortium blockchain is a specific blockchain with multiple authorised nodes to establish the distributed shared ledger at moderate cost. A consortium blockchain is established on authorised nodes to publicly audit and share transaction records without relying on a trusted third party. Food transaction records among user nodes are uploaded to the authorised nodes after encryption. The authorised nodes will audit the transactions and record them into the shared ledger. This ledger is publicly accessed by nodes connected to the consortium blockchain. Moreover, as the trading portfolios of merchants need to be optimised, an algorithm for iterative optimisation of transaction matches is designed to maximise the demand of buyers in the system. The contribution of this paper is summarised as follows.

- To protect the safety of the transactions, we use consortium blockchain technology to design new architectures that meet the challenge of different authentications and permissions for different roles in food transactions.
- For the purpose of helping users find suitable transactions and improving transaction efficiency , we have designed a improved Practical Byzantine Fault Tolerance (iPBFT) algorithm, and we have used the online double auction mechanism to eliminate competition.
- In order to evaluate the effectiveness of FTSCON, we conducted a case study to investigate the relevant enterprises in Shandong Province, China. The results show that the system has high commercial value.

The rest of this paper is organised as follows. Section 2 details related work. Core system components are illustrated in Section 3. Implementation details are discussed in Section 4. Section 5 presents the experiment platform, case study. The paper is concluded in Section 6.

2. Related Work

2.1. The Importance of Agri-Food Trade

The agri-food trade is an important part of the global economy. Most countries need to import and/or export agri-food. According to the latest statistics, EU exports of agri-food products reached €138 billion last year, an annual increase of 5.1%. In addition, the EU's agri-food imports increased 34% year-over-year in 2017 [20]. For resource-poor countries, such as Japan [21] and countries where agriculture is the backbone of the economy, such as Nepal [22] imports and exports of agricultural food are of vital importance to the development of the national economy. Bojnec et al. concluded that agricultural export growth is an important part of global agricultural food export growth through analysis of the agricultural food trade of 27 EU countries [23]. Crescimanno et al. examined the competitiveness of France, Italy, Spain and Turkey in the global agri-food market and how it changed in the wake of the economic and financial crisis using the relative trade advantage index. The results confirm, above all, that the firmness of a productive sector plays a crucial role in helping a country to face an economic recession [24].

2.2. Technology in the Agri-Food Sector

To ensure the steady development of the agri-food industry, technology is increasingly applied in the industry. There are some technical means to improve the efficiency of trade. For instance, innovative business information systems (BIS) were introduced into the agricultural food sector to enhance the competitiveness and practicality of companies [25]. Other technologies are used to build food traceability systems. The main beneficiaries of such systems are consumers. The degree of consumer support for a food traceability system or the consumption of traceable foods will directly affect the formulation and implementation of the system [26]. Recently, the use of radio frequency identification (RFID) technology in the food supply chain has been proposed [27,28]. At present, most of the solutions to food trade problems are from the perspective of the food supply chain. Such solutions include, among others, electron spin resonance (ESR) [29]. They help regulators gather and manage information to a certain extent, but they mostly target food traceability, food standards, risk assessment and food inspection. This leaves a gap, which the Internet of Things (IoT) is well-positioned to address by improving existing systems and tools [30]. Li et al. [31] formulated a tracking method for prepackaged food based on IoT, which tracks prepackaged food products to monitor the entire supply chain. In addition, Pang et al. [32] use an IoT design for a food supply solution. These technologies suffer from some obvious drawbacks: centralisation of data storage increases susceptibility to leaks and tampering, and the opaqueness of the transaction introduces doubt. Furthermore, the problems of information asymmetry and high privacy risk remain. Currently, there is no system that allows multi-stakeholders to participate while providing privacy protection and guaranteeing the transparency of transactions. However, blockchain technology can overcome these defects perfectly.

2.3. The Concept and Purpose of Blockchain Technology

Blockchain can be used in many fields. For example, a multimedia blockchain is used for media transactions [33], and the M2M electricity market is facilitated by blockchain technology [34]. Blockchain technology is more and more important to food trade. It could represent a legitimate option for farmers who feel compelled to rely on marketing boards to sell their commodities. The use of blockchain could prevent price coercion and retroactive payments, and it also can eliminate middlemen and reduce transaction costs [35]. This can lead to fairer pricing and even help smaller outfits desperate for more market attention. Information asymmetry is an inevitable problem in the food market. Hobbs [36] has pointed out that information asymmetry can cause failure in the food market, with the risk of consumers adversely selecting lower-quality (or unsafe) food in the absence of high-quality information relating to food quality. However, blockchain technology can reduce asymmetric access to information because all blockchain participants have access to the same information. For instance, it offers the possibility to better monitor and have access to information about product quality or provenance, which should facilitate exchanges [37]. Several existing applications combine blockchain and food technology, with the primary idea being to solve food safety issues. Major corporations have supported this idea. Walmart, Nestlé and IBM have formed a global food safety blockchain alliance. Their motivations are consistent with their objective of building a safe, sustainable and transparent food supply chain. The main responsibilities of the alliance are monitoring the supply chain, which involves storing supply chain data in the blockchain [38], and leveraging RFID technology to manage the supply chain using the blockchain [39]. In addition, blockchain can greatly improve traceability efficiency in food trade. Walmart, which sells 20% of all food in the U.S., has just completed two blockchain pilot projects. Prior to using blockchain, Walmart conducted a traceback test on mangoes in one of its stores. It took six days, 18 hours and 26 minutes to trace mangoes back to their original farm. By using blockchain, Walmart can provide all of the information desired by the consumer in 2.2 s. Blockchain technology also allows specific products to be traced at any given time, which helps to reduce food waste. For instance, a system based on hazard analysis and critical control points (HACCP) for food supply chain traceability uses blockchain and IoT to quickly and easily trace polluted products, while safe foods remain on the shelves and are not sent to landfills [40].

2.4. The Concept and Purpose of Smart Contracts

Smart contracts are a potentially revolutionary type of application using decentralised ledger networks. They are self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code. The code and the agreements contained therein exist across a distributed, decentralised blockchain network. Smart contracts permit trusted transactions and agreements to be carried out among disparate, anonymous parties without the need for a central authority, legal system or external enforcement mechanism. They render transactions traceable, transparent and irreversible. Smart contracts are often said to herald the era of blockchain 2.0. Karajovic et al. [41] have applied smart contracts to automate taxation and optimise accounting processes. Smart contracts can also be used as automatic custodians of digital assets or in executing contractual obligations in a safe, verifiable and deterministic manner [42]. An effective mechanism of using smart contracts to automate transactions does not yet exist but has been the topic of extensive research attention recently. It is also the subject of this paper.

Preparatory research and analysis make it clear that it is necessary and feasible to incorporate blockchain technology into food trading systems. The initial approach of this study was to introduce a public blockchain because such a blockchain is readable by any party; any user can initiate a verifiable transaction, and any user can participate in this consensus process. Such an automated trading system takes advantage of all the benefits provided by public blockchains. Further research, however, shows that, for an excessive number of nodes, the processing speed of the background system will diminish when all nodes are required to run a consensus algorithm, possibly causing harm to the underlying system. Furthermore, for transactions with a high volume of data, efficiency is reduced since each node stores the same data.

Based on a thorough analysis of the benefits and drawbacks of several blockchain mechanisms, the authors decided to utilise consortium blockchain technology for the study's automatic trading system.

3. Consortium Blockchain for FTSCON

Blockchain technology is a modern P2P technology with applications in distributed computing and decentralised data sharing and storage. Prior to recording a transaction in a blockchain, a process called consensus processing is applied to verify the data. This process is traditionally carried out by all nodes of the system, and the traditional transaction process contains multi-stakeholders. These are problems that increase costs and degrade efficiency. The system described herein is designed to solve these problems perfectly. The architectures for FTSCON include the following entities, as shown in Figure 1.

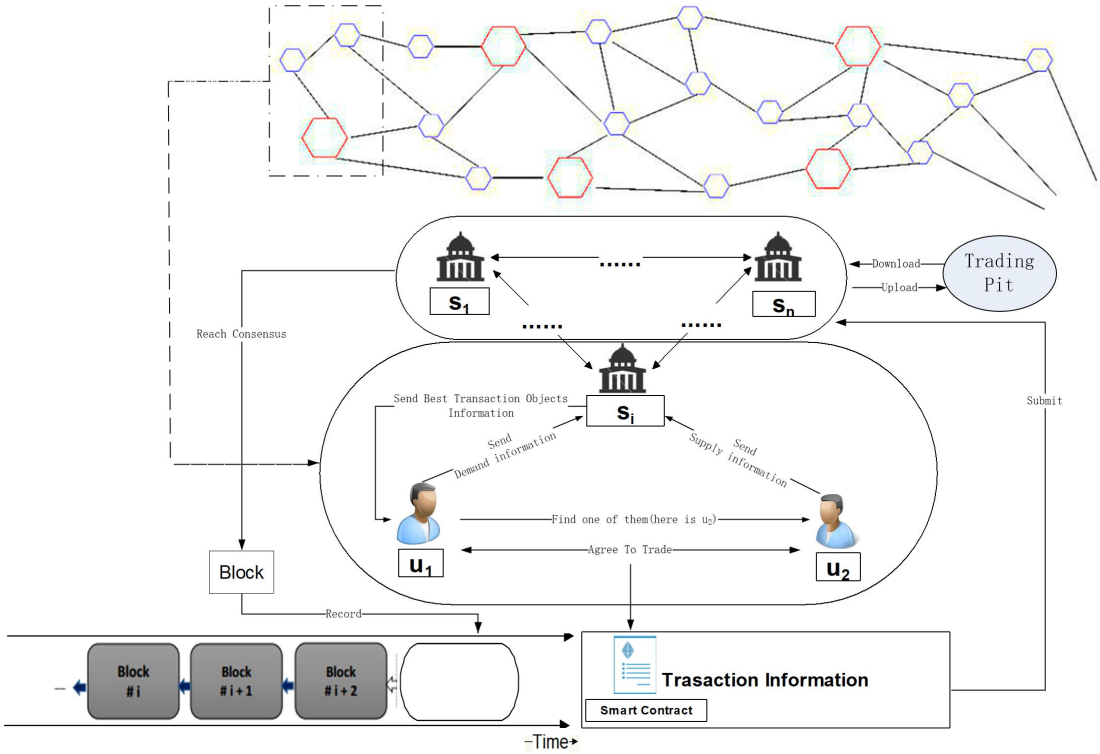


Figure 1. FTSCON.

(1) *User Node:* User nodes can play two roles in the system: buyer node or seller node. The role is chosen according to its current state and planning. In this paper, the buyer node is denoted by u_1 and the seller node by u_2,

(2) *Scheduling node:* The scheduling node has the authority to verify transaction data and calculate optimal trading objects for the users of the system. The scheduling nodes are represented as s_i (i = 1, 2, ..., n).

The consortium blockchain is made up of three parts:

(1) *Block containing the transaction data:* The scheduling nodes contain the bulk of the raw data. Computational and storage limits make it necessary for the user nodes to store an index of the metadata containing the metadata location to bring down system cost. The scheduling node manages local transaction records, which are encrypted and assembled after the scheduling nodes have reached a consensus. A cryptographic hash in each block points to the previous block, enabling validation and traceability. Blocks are added to the chain chronologically. Because of this, both scheduling and user nodes can access the data freely.

(2) *Consensus mechanism:* This is a mechanism that enables consensus to be achieved among blockchain nodes across the entire network, based on block information. It can be used to ensure that the newest block has been added to the chain properly and that the chain data stored in the nodes have not been maliciously forked or altered.

(3) *Smart contract:* Within the blockchain context, smart contracts are scripts stored on the blockchain. (They can be thought of as roughly analogous to stored procedures in relational database management systems.) Since they reside on the chain, they have a unique address. We trigger a smart contract by addressing a transaction to it. It then executes independently and automatically in a prescribed manner on every node in the network, according to the data that were included in the triggering transaction.

The portion of the Figure 1 containing set s denotes a group of scheduling nodes, while the portion containing u_1, u_2 and s_i is a schematic of the transaction process. The bottom left contains the block with transaction information, while on the right is the transaction data module.

4. Details of the Food Trading System

4.1. The Method of Optimal Transaction Combination

This section explains how a scheduling node is made to reach the consensus it needs to find the user's optimal transaction combination, automatically conduct the transaction through the FTSCON and verify the transaction information.

4.1.1. Problem Formulation

To ensure market fairness and stability, we prescribe that the rights and obligations of buyers and sellers are the same. Let v be a measure of a buyer's loss in transit; multiple factors can change this value in the real world, but there are two factors that have a higher bearing on the final v value. Here, freight and other charges are assumed to be borne by the buyer. However, in actual situations, these costs are mostly borne by the seller. To ensure consistency between the system and the facts, in this case, the authors stipulate that the expenses for the buyer are the opposite number of the expenses borne by the seller. Under this assumption, the value change during transportation (ν) will be calculated according to the formula shown below (Equation (1)). The algorithm is based on the formula below:

$$\nu = -(\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} + \lambda * \omega) \tag{1}$$

The two terms of the formula are the transport cost and the loss in value of the food caused by the transport time, where c_{ij} is the unit freight shipped to each place, x_{ij} is the quantity of food transported to various places and i, j represent the origin label and the place of sale label, respectively. Here, λ is the loss in value of the unit shipping volume, and ω represents the total shipping volume.

Transportation Costs

To select the appropriate transit cost, we analyse in detail the actual demand and supply states. The demand of one user can be satisfied by several suppliers, and several users' demands combined can constitute a supplier's supply. The following two situations can be considered:

(1) Demand and supply are in balance. The resultant mathematical model for minimum transit cost is the first term in Equation (1). The system calculates the transit fee and adds it to the corresponding value according to this formula:

$$s.t = \begin{cases} \sum_{j=1}^{n} x_{ij} = a_i (i = 1, 2, ..., m) \\ \sum_{i=1}^{m} x_{ij} = b_j (j = 1, 2, ..., n) \\ x_{ij} \geq 0 (i = 1, 2, ..., m. j = 1, 2, ..., n) \end{cases} \tag{2}$$

where the food production of i is equal to demand a_j, and the food sales of j are equal to supply b_j.

(2) Demand and supply are not in balance. In this case, we use a method to convert it into a balanced state. A sale location $n+1$ can be added in which to sell excess quantities and achieve balance. The cost of transit has no bearing on the sale price; that is, $c_{i,n+1=0}$ (i = 1, 2, ..., m). Therefore, the equation is still satisfied.

The Food Value Loss Caused by Transport Time

Wang's research states that the shelf life of food makes it a time-sensitive commodity [43]. As a result, transportation time is also a significant factor. Usually, excessive transportation time is considered to be detrimental to the value of food, because of both the basic cost of the food and the added overhead of storage, transportation and reduction in viable shelf life. In other words, food is a special commodity with time-variant value; in addition to transit time, market conditions during sale also affect its value. All of these factors will cause value loss for buyers.

To calculate the impact of transit time, the transportation method or path comparison method is used to calculate the value of the product at the time of transportation. The formula is the second term in Equation (1). The function of λ is:

$$\lambda = \frac{\alpha}{\beta} \tag{3}$$

where α and β are the commutative law of transport cost and time [43].

4.1.2. Algorithm Implementation

The proposed algorithm is derived from dynamic programming (DP), which is a very useful tool in solving optimal control problems. It is an algorithm attributed largely to Bellman, and is developed for optimising a multi-stage (the term stage represents time step throughout the paper) decision process. If the return or cost at each stage is independent and satisfies the monotonicity and separability conditions, the original multi-stage problem can be decomposed into stages with decisions required at each stage. The decomposed problem then can be solved recursively, two stages at a time, using the recursive equation of DP. DP is particularly suited to optimising reservoir management and operation, as the structure of the optimisation problem conforms to a multi-stage decision process. Over the past half-decade, DP has been used extensively in the optimisation of reservoir management [44] and operation [45].

In reality, buyers' demand is often met by multiple kinds of agricultural products rather than by a single kind. In most cases, a single supplier can only provide one or more agricultural products, so it cannot meet the demand of buyers. To calculate the correct number of suppliers to meet the demand, core issues need to be addressed. It was found that, if the ν and demand volume n of the buyer are controlled, and under the condition that the total demand of the buyer is N, the equation is defined as follows:

$$f[i][n] = \begin{cases} 0 \\ f[i-1, n] \\ \max\{f[i-1][n], f[i-1][n-n[i]] + v[i]\} \end{cases} \tag{4}$$

The 2D array $f[i][n]$ represents the minimal value change of food i to the buyer. The current demand of the buyer is n. It is assumed that the previous $i-1$ pieces of food have all been selected, and the current value change is $f[i-1, n]$.

4.1.3. Bargaining Process

After the scheduling nodes select the transaction combination for the buyer, the buyer and the seller need to negotiate the price. The seller's quote directly affects his own profits and whether the cost can be accepted by the buyer. Sellers must weigh the bidding strategy to maximise profit.

The seller only knows with certainty his own cost function, the payment function, the buyer's decision-making type space, etc., and vice versa. Obviously, the game between the seller and the buyer is a dynamic game process. In the actual price negotiation, the bid prices of the negotiating parties are not simultaneous; one party gives a price, which the other party chooses to accept or reject. If the price is rejected, the other party can give his own price, and they continue in this manner until the conclusion of the negotiations. For the bargaining game between the seller and the buyer, it is clear that the seller makes the first quote, and the buyer starts from his own profit maximisation goal based on this price to decide whether to accept it. If the buyer accepts the price, they will use the smart contract to execute the transaction; otherwise, it enters the next round of the bargaining game. Hence, this is a dynamic process of rotating bidding. The profit function of buyers and sellers is as follows:

Assuming that the number of bargaining rounds is N, in the N round, the buyer's bid price is ${W_{n/2}}^b$, and seller's accept price is ${W_{n/2}}^s$. We use W_s and W_b to indicate the seller's and buyer's expectations for the price of the food. The transaction may be executed when $W_s \leqq W_b$. Here, when N is odd:

$$\begin{aligned} r_1 &= \delta^{n-1}({W_{(n+1)/2}}^s - W_s) \\ r_2 &= \delta^{n-1}(W_b - {W_{(n+1)/2}}^s) \end{aligned} \tag{5}$$

and when N is an even number:

$$\begin{aligned} r_1 &= \delta^{n-1}({W_{n/2}}^b - W_s) \\ r_2 &= \delta^{n-1}(W_b - {W_{n/2}}^b) \end{aligned} \tag{6}$$

r_1 and r_2 are the profits of the seller and buyer, respectively, and δ^{n-1} is a coefficient of convergence, that is, the coefficient of return after refusal. Otherwise, both parties would bargain countless times to obtain the lowest price.

4.1.4. Online Double Auction Mechanism

In the actual transaction process, there are transaction object combination results that may satisfy the requirements of multiple buyers. There will be competition among different buyers. At this time, the online double auction mechanism is used. The double auction mechanism can solve problems such as effectively using network resources and lightening the network load. In contrast to unilateral auction, double auction is characterised by a "many-to-many" market structure. That means there is more than one buyer and seller. It is an inter-networking information exchange model where auctioneers and bidders are equal.

The process is as follows: The scheduling node opens the market, buyer nodes and proxies (here, proxies are chosen by seller nodes in the transaction combination) randomly quote, and the scheduling node collects quoted prices and picks the current highest price of a buyer and lowest price of a proxy. As soon as the highest quoted price of a buyer is higher than or equal to the lowest proxy quote, the trade is executed immediately. The process continues until all transactions are completed and the market is closed. In this paper, we find that loopholes such as serious asymmetry in information between buyers and sellers in the auction process [46] are perfectly fixed. Based on the work of Fu [47], the formula for the maximum auction efficiency is as follows:

$$\begin{aligned} a_i &= \frac{2}{3}v_i + \frac{1}{4}V_{min} + \frac{1}{12}V_{max}, \\ b_i &= \frac{2}{3}m_j + \frac{1}{12}V_{min} + \frac{1}{4}V_{max}. \end{aligned} \tag{7}$$

where a_i denotes the quotation of the i buyer, v_i denotes the estimated price of the i buyer, V_{min} denotes the lowest bid announced by the market, V_{max} denotes the highest quotation, b_j denotes the quotation of the j seller, and m_j denotes the j seller cost.

After the auction is finished, the transaction price is determined and a smart contract is generated by the system.

4.2. Smart Contract and Consensus Process

Smart contracts can be considered a set of digital promises. For a user, a smart contract is effectively an automatic guarantee by which, for instance, information is shared when specific conditions are satisfied. It is a programmable contract between two parties that is stored in the blockchain and tagged with a bespoke blockchain address. The contract is executed when its conditions are met. Smart contracts are stored in blockchain and require consensus on nodes. This mechanism improves trust between users due to the credibility of the blockchain. A well-known challenge for blockchain is that the blockchain network is distributed, and there is no central node that ensures ledgers on distributed nodes are all the same. Some protocols are needed to ensure ledgers in different nodes are consistent. We next present three common approaches to reach a consensus in blockchain.

This paper proposes an improved PBFT (iPBFT) algorithm whose underlying principle is using the automatic transaction mechanism of the system to verify transaction information. It can be seen in Figure 1 that the transaction is verified by u_1 and u_2 after completion, after which both encrypt and upload the transaction data to the nearest scheduling node s_i, which verifies the information based on its cache table, signs and timestamps it if the verification is successful, and then sends these data to other scheduling nodes. If the number of signed nodes is more than half of the total nodes (such as 51%), consensus is said to be reached, after which the transaction is recorded in the block and the block is appended to the blockchain (as show in Figure 2).

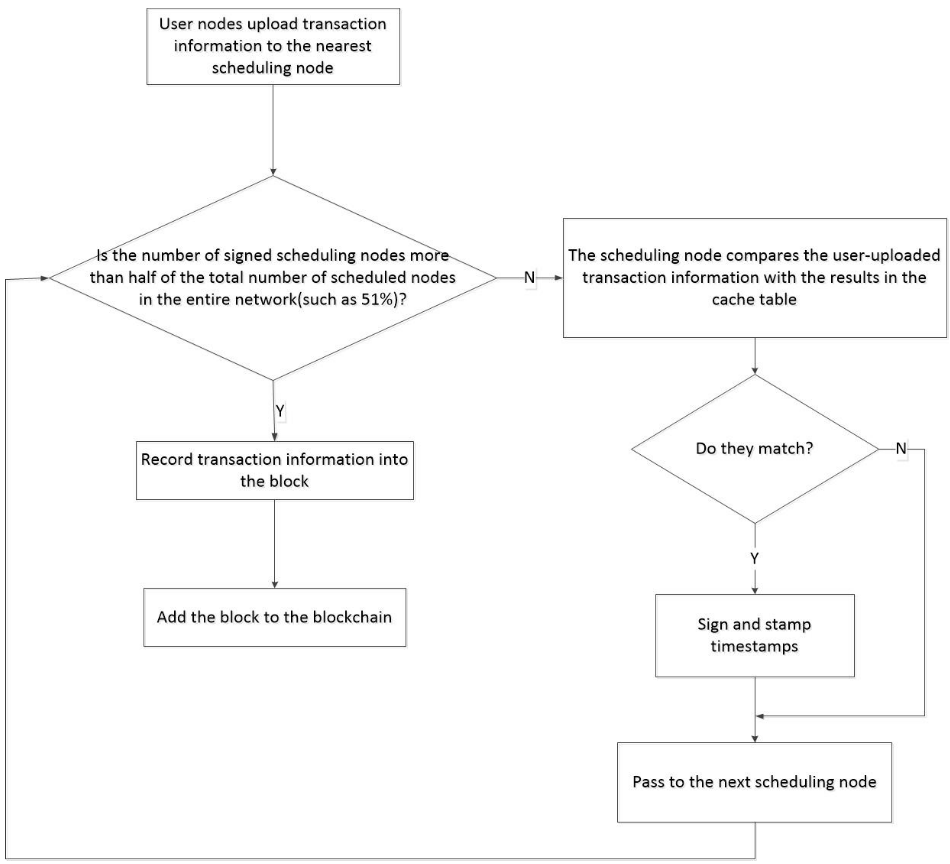


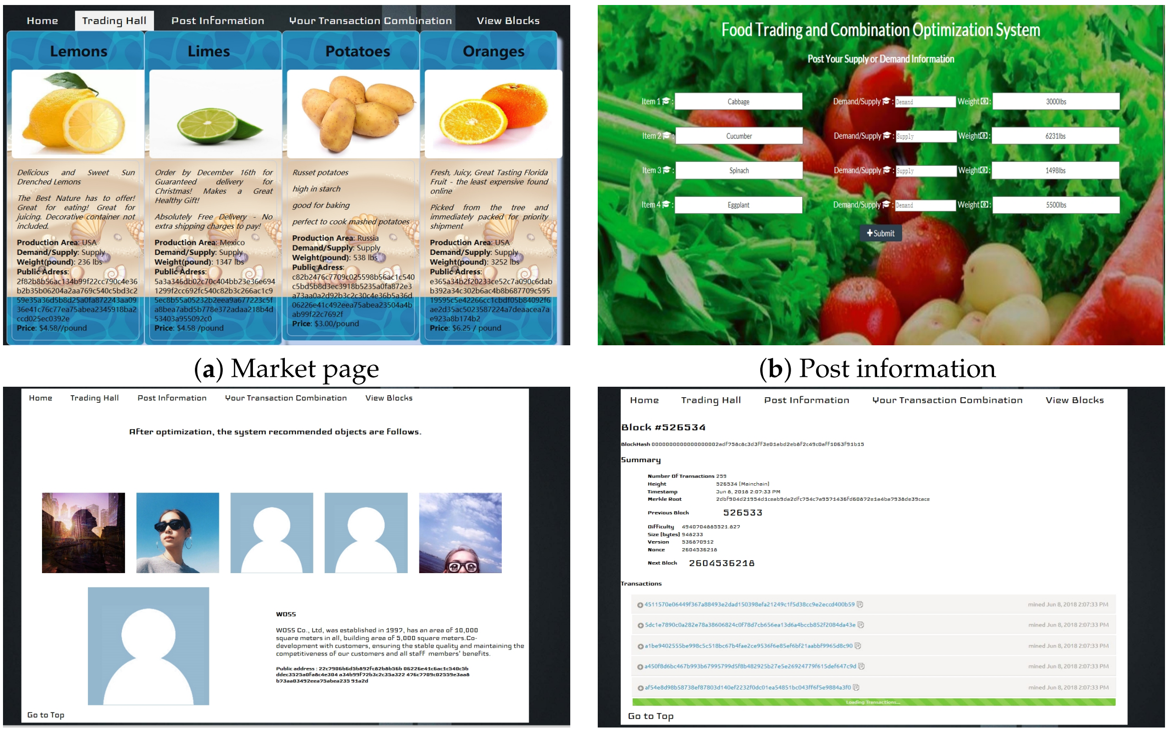
Figure 2. The process of iPBFT.

5. Experiment Platform and Case Study

5.1. Experiment Platform

Ethereum is a blockchain with a built-in Turing-complete programming language, giving users power to write smart contracts, decentralised applications where users define their own arbitrary rules for ownership, transaction formats and state transition functions. Ethereum also has provided tools for building consortium blockchain. Thus, we deployed an Ethereum consortium blockchain residing on multiple virtual machines running Ubuntu Linux v14.04 in an Openstack environment. Each virtual machine was given 1 virtual CPU core, 2 GB of memory and 10 GB of persistent storage to meet the minimum hardware requirement for running Ethereum. Elastic Search was used to store block-related information. The network behaviour was monitored using the Python Web3 Library. All virtual machines are linked together in a low-latency local network that can be customised on demand. Our setup peers every node using a single Gigabit Ethernet switch. With this setup, the communication round-trip time between every two nodes is less than 1 ms on average. We employ Linux traffic control to introduce delays to emulate high latency in mobile networks and configure the Linux kernel firewall with Iptables 9 to emulate churns. We used Geth v1.6.4 10 for all of our empirical evaluations. Before the actual experimentation, we let the system stabilise for a few hours to obtain appropriate parameters in later runs. To form a fully connected P2P blockchain network, we disabled the autodiscovery feature supported by Geth and configured the overlay network manually.

The FTSCON, including consortium blockchain, Web server and client browser, was built by Ethereum architecture. The Web server was developed by PHP. The client browser page was written using HTML/CSS/JavaScript. Consortium blockchains are designed to record transaction information, node data, transportation process and time. The optimisation of transaction combinations is made in the consortium blockchain. A Web server is responsible for collecting supply/demand data, block data, real-time in-auction data and node feedback data. The client browser is responsible for friendly display, interacting with nodes and collecting node transaction intentions (see Figure 3).



(**a**) Market page (**b**) Post information

(**c**) Transaction objects (**d**) Block information

Figure 3. Screenshots of FTSCON interface.

5.2. Case Study

Our case study data were provided voluntarily by 300 small- and medium-sized agri-food enterprises in Shandong Province. The data include profits between January 2014 and December 2017. In total, 14,382 profit data items were collected. The data also cover the type of transaction products in terms of species (e.g., wheat, corn or soybean), the weight of transaction products, a description of the location (region, spatial coordinates and location type) and the timestamp of the transaction. The specific data format is shown in Table 1. The three sets of data here show the supply of wheat by Company A on 12 and 16 May 2017. To protect the privacy of the enterprise, the company name and other related data are processed and given a general description. The general geographical distribution of enterprises is shown in Figure 4. In this figure, the red dots show the distribution of enterprises and the numbers represent the number of enterprises involved in this study.

Table 1. Data format of profit.

Company A					
Number	**Product Type**	**Weight**	**Price (RMB)**	**Location Sold**	**Time**
1	wheat	4000 lbs	5200	Liaocheng	12 May 2017
2	wheat	6000 lbs	8100	Jinan	16 May 2017
3	wheat	3500 lbs	4620	Taian	16 May 2017

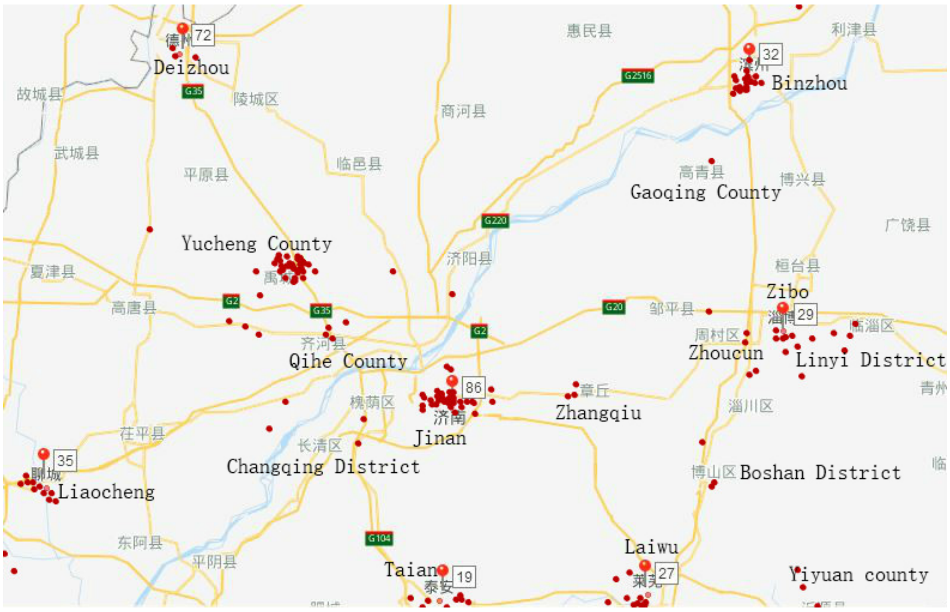


Figure 4. Food enterprises of Shandong Province in this study.

The project analysts also calculated the profit outcomes due to the use of FTSCON functionalities, i.e., the total profit of different enterprises in the region before and after the use of the system in the same quarter. Within the analyses, the data from the first year of FTSCON use (2017) were compared to the average data of the three years preceding the integration of FTSCON (2014–2016). Figure 5 displays the comparison results that were able to provide reliable data from the Web server.

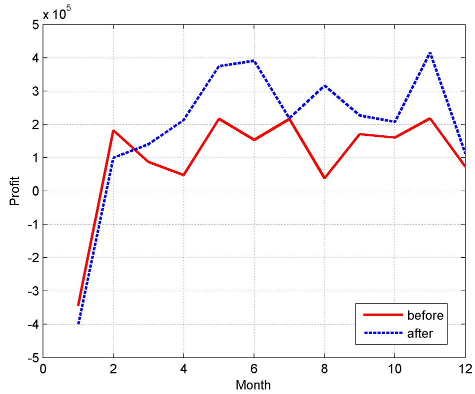


Figure 5. Quarter-wise profits with and without FTSCON.

It can be seen that January losses were higher using the existing trading model, and the February profit was lower as well. From March onwards, the profit curve using the proposed system rose, with a higher monthly profit than the traditional system. Even in months with a declining trend, such as July, September, October and December, the proposed method provided better profits than the existing one. Thus, we draw a conclusion that site selection is one of the most important decisions for the establishment of an enterprise operation. The production location influences the competitiveness of the farm and enterprise by conditioning environmental and economic factors. The influence of environmental factors on crop growth has implications for the time required to reach the desired commercial size and, therefore, for the costs associated with the cultivation process. The most investigated factor is the transaction strategy, which is the characteristic with the greatest influence on the food trade rate. In addition to these factors, food transactions are also affected by seasonal factors. Moreover, FTSCON can also help merchants to destock and eliminate deficits.

Next, the authors used the profit data of 300 food enterprises in 2016 for further research. After analysis of a series of variables influencing the profit rate, the variables that can affect profits of food enterprises were determined. Econometric software was used to calculate the correlation coefficient of each variable, and the regression model before and after using FTSCON was established. In the regression equation, one-year's profit rate is taken as the dependent variable of the equation. Through linear regression, the estimated profit rate (lower limit of profit) and revised profit rate (upper limit of profit) after using the system were obtained. The consent of 15 companies was obtained, and their relevant data are shown in Table 2.

From the data provided in Table 2, it can be seen that the profit rate after using FTSCON is generally significantly higher than the actual profit rate. For example, the actual profit rate of Company 3 is 5.4%, and the estimated profit rate after using the system ranges from 8.4% to 22.8%. The actual profit rate of Company 7 is 10.2%, and the profit rate after using the system ranges from 13.0% to 27.0%. The actual profit rate of Company 15 is 10.6%, and the profit rate after using the system ranges from 11.2% to 25.2%. To better explain the results, the profit rate ranges of each company after using the system are treated with median processing. The resulting data are shown in Figure 6 along with the actual data.

Table 2. Profit rate comparison.

Company	Nominal Profit Rate	Estimated Profit Rate (Lower Limit)	Revised Profit Rate (Upper Limit)
1	0.01921177	0.016395052	0.139066229
2	0.05350845	0.088536898	0.206845791
3	0.05251345	0.084479413	0.227882558
4	0.08051790	0.100740364	0.227711578
5	0.04542092	0.043284216	0.184090319
6	0.06340454	0.079050859	0.217576012
7	0.10188542	0.130680734	0.270067289
8	0.05081418	0.040873076	0.163101822
9	0.02472651	0.062985808	0.217340049
10	0.04427022	0.059316479	0.160728596
11	0.05773707	0.083196925	0.216904303
12	0.04238949	0.003949896	0.158437023
13	0.03443118	0.040540996	0.154075249
14	0.03142729	0.018562336	0.153459196
15	0.10575547	0.112136786	0.252431141

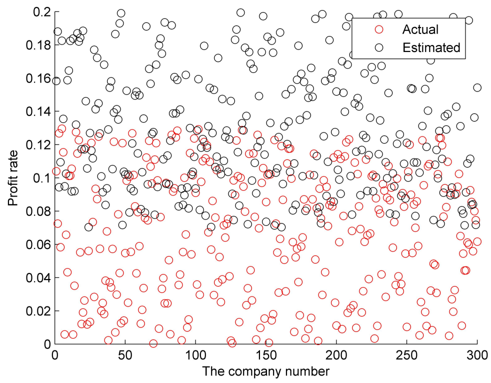


Figure 6. The profit rate of 300 food enterprises in one year.

As can be seen in Figure 6, most of the profit rates are within the range of 6% to 14%. Overall, however, the estimated median profit rate after using FTSCON is greater than the actual profit rate.

To better validate the effectiveness of FTSCON, we randomly selected ten groups from 300 sets of data for significance analysis. Variance analysis is a statistical method for analysing and processing the significance of the mean difference between multiple sets of experimental data. Its main task is to understand the impact of various experimental conditions on the experimental results through analysis and processing of data to more effectively guide practice and improve economic efficiency. Matlab r2014a was selected as the analysis software. The results of the analysis are shown in Figure 7.

It can be seen in Figure 7 that, in the case of the significance level $\alpha = 0.05$, the null hypothesis is that there is no significant difference between the two datasets. Since p(Prob>F) = 0.0049 < 0.05, the null hypothesis is rejected. There is a significant difference between the two datasets. In addition, it can be seen that the differences between the columns are significant, indicating that FTSCON has a significant effect. The differences between the rows are extremely significant, indicating that the difference in profit increase is extremely significant for these companies.

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	22.05	1	22.05	13.73	0.0049
Rows	2708.45	9	300.939	187.44	0
Error	14.45	9	1.606		
Total	2744.95	19			

Figure 7. Analysis of variance table.

6. Conclusions and Outlook

This paper proposes a food trade mechanism based on an alliance chain that helps to eliminate information asymmetry and guarantee market fairness. The proposed system is shown to be effective for the food trade field. According to the Sustainable Food Trade Association, a highly reputed agricultural sustainable development organisation, the organic sector must integrate environmentally sound, socially just business practices using a systems-based approach to reach its full potential. In addition, they state that the sustainable development of food trade involves the participation of a diverse mix of organic producers, processors, manufacturers, distributors and retailers, as well as related vendors, suppliers, aligned organisations and individuals. This paper provides an effective technical means to achieve the above requirements. Therefore, it has great academic significance for sustainable development research. In addition, it addresses trust issues in food trading because the proposed system ensures open transparency. For policymakers, FTSCON can better manage the food industry because it partly solves regulatory dilemmas. For multi-stakeholders in the food industry, including food importers and exporters, the system also uses the dynamic programming algorithm to select the appropriate combination of trading objects, and it uses the online double auction mechanism to improve their profits. Moreover, the transaction efficiency is improved through iPBFT. The security analysis shows that privacy in the transaction is well protected, and the case studies prove that FTSCON can significantly improve merchants' profits.

However, all current blockchains have problems related to computing resources, transaction costs, block speed and scalability. These problems lead to greatly reduced transaction efficiency under conditions of high transaction throughput. FTSCON is also limited by these problems, and solving them will be the next step of our work. Additionally, as computational costs of the on-chain matching algorithm depend on the amount of supply and demand information and cannot be determined in advance, a fair mechanism for the allocation of these costs has to be determined.

7. Patents

This work has been submitted applied for a patent. The patent number is 201810586692.0.

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Draft Preparation, D.M.; Writing—Review and Editing, Z.H.; Visualisation, Z.H.; Supervision, D.M.; Project Administration, D.M.; and Funding Acquisition, D.M.

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Abbreviations

The following abbreviations are used in this manuscript:

FTSCON	Food trading system with consortium blockchain
PBFT	Practical Byzantine Fault Tolerance
iPBFT	improved PBFT
BIS	Business Information Systems
RFID	Radio Frequency Identification
ESR	Electron Spin Resonance
HACCP	Hazard Analysis and Critical Control Points
POW	Proof of work
POS	Proof of stake

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