Supply Chain Resilience in IoT Context -Focus on Innovation of Food Supply Chains with traceability systems

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Abstract

In this paper, we conduct a systematic research on the characteristics of food supply chains in IoT context and analyse current status and problems of food supply chain, which has been attached higher importance in supply chain research in recent years. Then, we introduce and explain the establishment of food supply chains and their traceability systems through case studies in order to illustrate the availability and robustness of tracebility systems. After this, we investigate the feasibility and effectivity of blockchain technology which to innovate supply chain systems based on the studies of traceability system in food supply chain.

Keywords: Supply Chain Management in Food Industry; Innovative Technologies as Enablers of Sustainable Operations

Introduction

In recent years, food safety cases have repeatedly occurred, and it is imperative to adopt a safe, credible, and transparent food safety traceability system to strengthen the supervision and efficiency of the food industry chain, improving food safety and protecting national diet and health (Kannan Govindan, 2018; Louise Manning, 2018). The current food traceability system are confronted with problems such as non-standard information collection, insecure data storage, vulnerability of the central system, and the insecure protection of information exchange between enterprises. With the characteristics of distributed fault-tolerance, non-discriminability and privacy protection, blockchain technology can target at the problems existing in current food traceability systems.

The current food safety traceability system has always relied on authoritative government agencies to manage the central database, and the reliability of information transfer among various roles in food supply chain remains to be resolved. Take agricultural products as an example, the process of pre-production, mid-production, and post-production of agricultural products involves producers, processors, agencies and consumers. It is so complicated that food safety supervision and tracing are particularly difficult.

On the other hand, one obvious characteristic of contemporary social and economic development is the competition being more intense and the development of technological

progress being more rapid, prompting enterprises to make a series of changes in the field of logistics and purchasing and more companies to adopt the thoughts and methods of Supply Chain Management (SCM), which not only can reduce the operating costs of enterprises, raise the speed of response to market demand, but also can improve the competitiveness of enterprises in market competition. Nevertheless, there are still certain issues of concern in the operation of SCM, such as the low level of intelligentization of SCM, high degree of uncertainty, low automation of certain industries, frequent manual errors, serious industry losses, difficulties in tracing products after sales, and etc. The research and development of Internet of Things (IoT) bring new opportunities to the innovation of SCM (Riccardo Accorsi. et al., 2017).

The Studies of Food Supply Chain

In 1996, Zuurbier et al. first proposed the concept of food supply chain on the basis of supply chain, and considered food supply chain management as a vertical integration mode of operation conducted by organization of agricultural products and food production and sales for the purpose of reducing logistics cost of food and agricultural products and improving quality stability and level of logistics services (Zuurbier, 1999). The research on food supply chain management has gone through several phases: the first phase is business flow management phase, and research scope covers business flow phase from output of agricultural products and food processing enterprises to their delivery to consumers. The research content is usually concluded in marketing category. The next phase is integrated logistics management phase. The logistics management of agricultural products is separated from marketing and extended upstream to the process of production and processing in enterprises manufacturing agricultural products and food, emphasizing market-oriented production and cost control on the entire procedure of logistics. In the last phase, regarding integrated supply chain management phase, research scope extends further to the most upstream enterprises of agricultural products, the purpose of which is to follow and trace security issues regarding quality of agricultural products and food, so problems can be detected and solved effectively.

Factors of Food Supply Chain Emergence

The emergence and development of food supply chain is an inevitable result of continuously enhanced demand of food consumption in recent years. Consumers raise their demand on freshness of food and agricultural products, and require shorter delivery time and production period of food and agricultural products. Consumers also raise requirements on quality of food and agricultural products, forcing food manufacturers to implement food supply chain management to ensure stable upstream raw materials supply and smooth downstream sales channels (Jelena V.Vlajic. et al., 2012).

Consumers are paying much more attention to the quality and safety of food. To meet consumers' demands on types and quantities of food and agricultural products, enterprises are constantly exploring and developing new technologies, nevertheless, when consumer demands being fulfilled, excessive use of new technologies and methods (such as pesticides, hormones, antibiotics and genetically modified technologies) hazard human body and thus causes food quality and safety issues inevitably. Reason for this is information asymmetry between buyers and sellers in the market. In detail, when consumers purchase food or agricultural products, they lack product's hygiene, environmental and safety information. Therefore, it is necessary for enterprises to inspect and test products in all the phases of production procedure and disclose the information to consumers in time (J.H.Trienekens. et al, 2012).

Under the pressure from government, relevant social organizations and consumers, food and agricultural products companies have to follow food supply chain to operate. For example, according to EU Regulation 178/2002, food supply chain tracking should be conducted on all the foods traded within the EU from 2004 (EUR-Lex, 2018). In the United States, Food and Drug Administration (FDA) stipulates that department and related organizations engaging in food production, processing and packaging in the United States and abroad must register with FDA before December 12, 2003 for food safety tracking (U.S. Food and Drug Administration. et al., 2009). Those unregistered are prohibited from food production and sales. This indicates that food supply chain management is brought about by internal motivation from market and external pressure from government.

According to the definitions made by the International Organization for Standardization, traceability system can be expressed as: "a technical tool to assist an organization to conform with its defined objectives, and is applicable when necessary to determine the history or location of a product or its relevant components." (ISO, 2007). Food safety depends on every node in supply chain. Therefore, it is essential for every node firm to store relevant information of food production process for future reference. Traceability systems include internal traceability system and external traceability system. The former one refers to the tracing of products and relevant information within certain organizational chain of supply chain, such as quality traceability system of wholesalers' commodities, which is often a quality assurance system embedded in an organization. While the latter one is a vertical retrospective one across the entire supply chain, referring to the tracing of data and transaction process at every node.

Food Safety Traceability

Currently, there is no unified international definition of food traceability. The definition with relatively high industry recognition comes from CAC and ISO. The Codex Alimentarius Commission (CAC) defines food traceability as the ability to track food operations throughout designated production, processing, and distribution links. The International Organization for Standardization (ISO) defines it as the ability to trace a product's source, application, and location within the field to be considered.

In food supply chain, the main participants involved in the activities include: raw material suppliers, manufacturing companies, processing and manufacturing companies, distributors, and consumers. In accordance with the principle of "step forward, step backward" for food traceability, it is theoretically possible to realize the traceability or retrospection of relevant foods, feeds for food production, and edible animals or substances in food production, processing, distribution and distribution processes.

IoT-based Traceable Food Supply Chain

Previous literatures have made various elaboration on the concept of traceable food supply chain, illustrating characteristics, risks, processes, systems and operating mechanisms. Gandino et al. (2009) studied the impact of RFID on food supply chain traceability. Regattieri et al. (2007) established a conceptual framework model for traceability systems. Alfaro and Ràbade (2009) studied the inventory management of traceability system. Narsimhalu, et al. (2015) studied performance evaluation and optimization of traceability systems.

However, these are still conceptual model and theoretical analysis, in lack of empirical research. Therefore, on the basis of the existing, risk management of quality and safety on traceable food supply chain, process reengineering of traceable food supply chain based on IoT technology and the establishment of traceable food supply chain system

based on incentive mechanism should be focused on. Upon the systematical study on traceable food supply chain, an effective implementation and operation mode of traceable food supply chain is put forward against the security issues of food supply chain.

Some Problems during Implementing Traceability System

Previous traceability information appeals regarding production date, product quality conformity grade, additive content, and etc. still remain at a low-level. On the other hand, information concerning the detail of production place and the participants involved in production of process traceable products should also recorded, challenging the technologies of automatic collection of information and data storage.

To increase regulatory level of centralized food traceability system, various authoritative organizations and government agencies need to intervene and act as third-party trust brokers. This affects the efficiency of system operation, and the operation of the entire system will be affected by the security of central server.

The exchange of information among enterprises relies on third-party trust brokers, and due to the decline in social integrity of current supervisory authorities, the transparency and credibility of information exchange among enterprises is far from satisfactory.

Introduction of Blockchain

Concept of Blockchain

Blockchain can be narrowly interpreted as a decentralized, no need to trust, new data architecture (or shared account book) that is shared and maintained by all nodes in the blockchain network application (Maria-Lluïsa, 2017). Its technical features include decentralization, trust, collective maintenance and reliability. It consists of a series of data blocks generated on the basis of cryptographic method; data block is the term "block" in the blockchain concept. According to the chronological order the blocks are generated, the blocks are orderly linked to form a chain structure, and that is why it is called blockchain.

Basic Structure of Blockchain

The technologies involved by blockchain include distributed storage, cryptography, economics, game theory, network protocols, and etc (Kshetri, 2017). The blockchain system can be divided into data storage layer, network layer, contract layer, and application layer. The main technology involved in each layer is shown as in Figure 1.

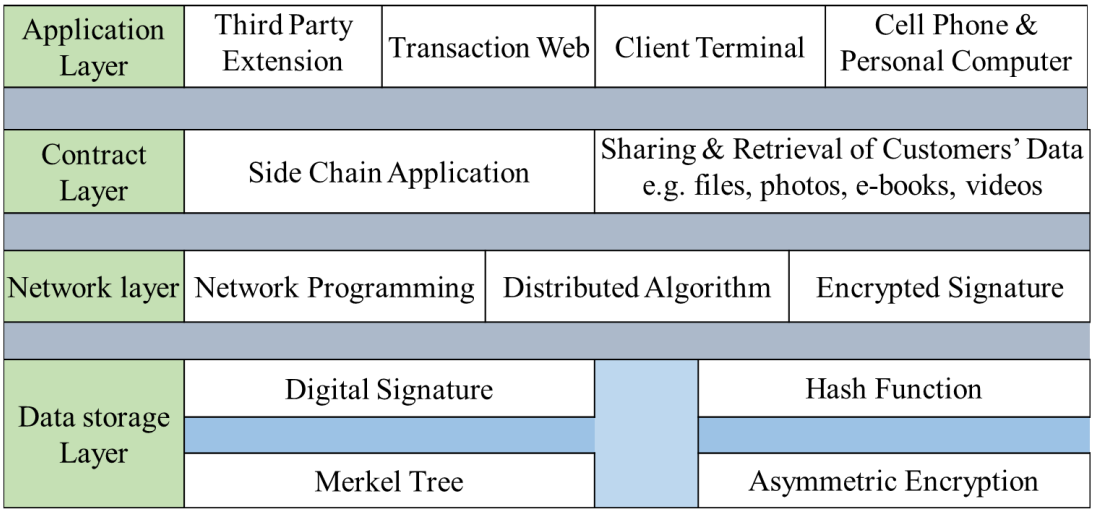

Figure 1: The Diagram of Basic Structure of Blockchain.

The data storage layer mainly encapsulates the contents of the underlying data blocks, timestamps, and related data, and is a guarantee for the security of information records. The network layer is responsible for the distributed networking mechanism, data propagation mechanism, and data verification mechanism. It is the structural basis of decentralized storage method.

The contract layer handles all types of system scripts, algorithms, and smart contracts, representing the programmability blockchain. Application layer encapsulates the blockchain application scenarios and cases.

The characteristics of blockchain are distributed storage and asymmetric encryption(Noguchi, 2017). With alliance chain, various regulatory agencies and organizations are introduced to rationally adjust the degree of decentralization and consensus mechanisms in blockchain. Accordingly, without complexing the food safety traceability system, issues such as the non-standard collection of information in the traceability system, insecure data storage, vulnerability of the centralized system, and the absence of privacy assurance throughout information exchange process among enterprises can be targeted and resolve.

Design of Food Safety Traceability System based on Blockchain

Basic Structure of Traceability System based on Blockchain

In terms of participants, firstly, each participant will set up a corresponding information file when registering, and the file contains information regarding employer, position, address, and qualification. After successful registration, the participant will receive a public key and a private key. The public key is disclosed to all the members of blockchain, and the private key is the key to verify identity and information during the transaction. All the participants can use the registered ID to log in to the user interface and enter the specified blockchain network (see Figure 2).

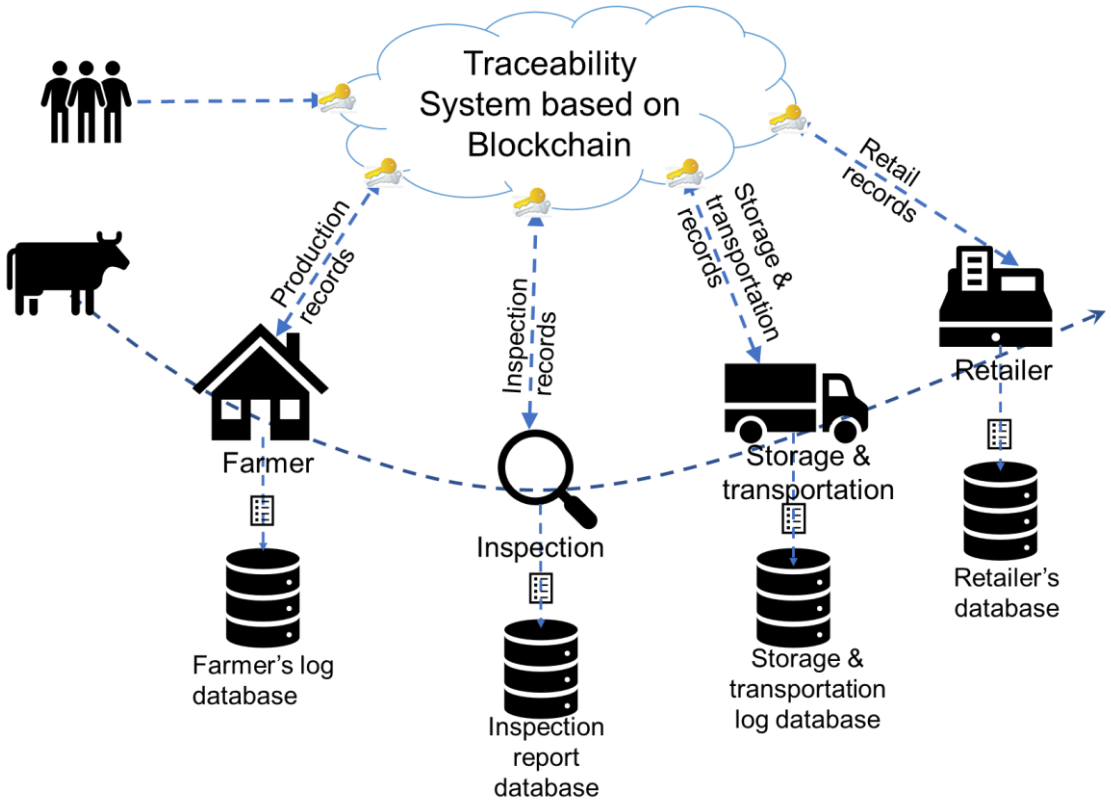

Figure 2: The Structure of Traceability System based on Blockchain

In terms of information flow, all the information is stored in blockchain and is supported by authorized nodes. The right to access information depends on the participants' roles and positions in supply chain. In addition, the operation rules of blockchain are defined by the codes and stored in blockchain, which cannot be modified by a certain participant in blockchain, hence the authenticity and validity of data are ensured. If operation rules of blockchain need to be changed, then just like the way data being storaged, broadcast needs to be made to all the nodes and verification needs to be performed by the key departments.

The significance of the alliance chain

Obviously, the food traceability chain will involve agencies and enterprises at different levels of privileged roles, thereby reiterating the significance of the alliance chain. The difference between the alliance chain and the public chain lies not only in system centralization and participant identities, but also in the differences in consensus mechanisms and incentive mechanisms.

The trust mechanism in the blockchain system is no longer required to be PoW or PoS. By reducing the degree of decentralization, the number of nodes participating in the consensus mechanism can be lowered, and the waste of resources in mining process can be eliminated accordingly (Kshetri, 2018).

Maintaining the food traceability system is the responsibility of all the participating nodea in alliance chain. Therefore, the operation of the blockchain system does not require an incentive mechanism. That is, with alliance chain, there is no need for digital currency any more, hence the recording of ledger books is simplified, and the bandwidth required for system operation is reduced.

Analysis of Operating Mechanism

Product Identification

The basis for the operation of the food traceability system is product identification and coding. Effective tracking and retrospect can be achieved if and only if the product is correctly identified.

Adopting the EAN UCC system to identify products not only can improve the standardization level of product coding, but also guarantees the compatibility between blockchain-based food safety traceability systems and traditional systems, which is beneficial for enhancing the adaptability of new systems in the market (IBCA, 2018).

Both the barcode technology and RFID technology support the identification of the product's system ID by scanner and link to the product's electronic information file, automatically entering data into the system.

Data Entry Process

In the envisaged traceability system, each commodity, including its identity and parameter information, are digitized in the blockchain network. Information maintainers can maintain the product information comprehensively and avoid the fragmentation issue of the traceability information. With product and participant IDs, the certification authority can automatically open access for the current responsible node of the products through intelligent contracts, ensuring the orderliness and reliability of data maintenance, preventing irregular operations of non-relevant nodes, thereby achieve orderliness and

reliability of system and comprehensive traceability of products and maintenance of product information.

When an authorized participant maintains a product information document, it is required to input data information on the software application interface after connecting to the network with a private key. The system collects a series of information, including the current status of the product, the type of the product, and the industry standard to which it is based. Once participants initiate product transfer, the system checks the validity of the data format and compliance with industry standards through embedded smart contracts. If the verification is successful, the information previously provided by the participant is packaged and entered.

In summary, both the internal information maintenance and the inter-company transaction process of the company can record operation logs through the blockchain. The timestamp technology and asymmetric encryption technology ensure the reliability and mothproofing of the food traceability system based on the blockchain technology.

Case Analysis

We proposed a food chain traceability system based on blockchain as above, and its operating mechanism has been briefly introduced. In the following part, we will depict the work flow of the traceability system with a real case. The Japan Gibier Promotion Association (JGPA), which deals with system construction, to utilize benefits of difficult tampering for food traceability (PR TIMES, 2018).

Formulating Upstream of Food Supply Chain in the Traceability System

As a food supply chain of livestock, it includes the participants such as suppliers, processing companies, and distributors. What needs to be stated is that the complexity of the food supply chain determines that there are many branches in its main chain.

Then, the application of blockchain-based food safety traceability system will be introduced. The main role is the livestock farm. The farm first identifies all the livestock and poultry and inputs their information into blockchain, completes the creation of their own product information file, and then enters information regarding livestock and poultry's birth, feed, dispensing, disease, sales, and etc.

Once the livestock and poultry are sold and flow to the next step, the current responsible party initiates a transaction request and uses the private key to sign the smart contract embedded in the blockchain with the slaughterhouse. The system records the transaction operation, and after the transaction is completed, the receiving party is automatically authorized. The slaughterhouse becomes the new authorized party responsible for following up the product and maintaining the product information document.

Among them, the inspection of immune information should be the same as the cultivation link, and the certification body needs to be involved. In this session, the departments related to animal food inspection and immunization need to participate in the review and adopt digital signatures to certify product safety. In the deep processing process, in addition to slaughtered poultry, other raw materials such as additives will be introduced.

Formulating Downstream of Food Supply Chain in the Traceability System

The next step is product packaging. During this process, physical information such as product packaging materials, packaging time, and volume weight must be added. In addition, physical tags need to be generated for the product to provide consumers with a query entry.

A product may have to go through various distribution links to finally arrive at the retail link. Therefore, the sales company must clearly identify the source of the product and write it into the product information document. At the same time, sales companies should also supplement information of product sales time, price, and etc. to ensure the integrity of product documentation and the timeliness of information items in the blockchain system.

When a consumer purchases a product, he or she can access the product information document through a bar code, two-dimensional code, or RFID on the product package to learn the related information.

When a food safety incident occurs, the main role is law enforcement department. At this time, the relevant department obtains a higher level of authority through the private key, accesses the details of the product from the farm to the table, so as to determine the origin of the problem and accountability, or through detailed logistics and distribution information for precise product recall.

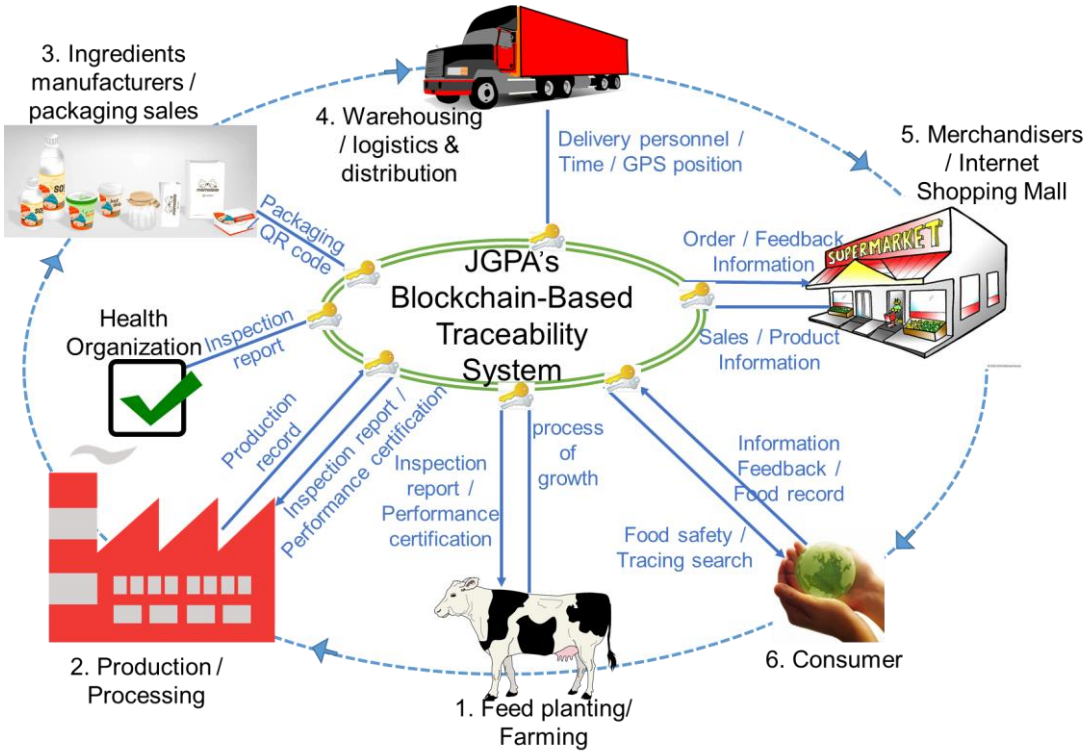

Figure 3: The Mechanism of JGPA's Traceability System based on Blockchain

Conclusion

In this paper, we conduct a systematic research on the characteristics of food supply chains in IoT context and analyse current status and problems of food supply chain, which has been attached higher importance in supply chain research in recent years. Therefore, a review and analysis of IoT-based food supply chains is conducted and an architecture of cold chain traceability system is proposed on this basis.

In the latter part of the paper, we innovatively proposed a blockchain-based food safety traceability system scheme. Starting from the top-level architecture of the traceability system, it describes the technical foothold of blockchain in the traceability system, and the degree of decentralization, consensus mechanisms, and other aspects in blockchain

are improved to overcome the shortcomings of the original blockchain (public chain), so that the application of the blockchain system in the food traceability system can exert its advantages without burdening the host system.

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