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

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AN INFORMATION SYSTEM FOR FOOD SAFETY MONITORING IN SUPPLY CHAINS BASED ON HACCP, BLOCKCHAIN AND INTERNET OF THINGS

DOCTORAL DISSERTATION

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Abstrakt

Mit dem starken Wachstum der chinesischen Wirtschaft wurde der Lebensstandard der Menschen kontinuierlich erhöht, was wiederum die Konsumgewohnheiten der Verbraucher veränderte und zu einer höheren Aufmerksamkeit bei der Lebensmittelsicherheit und -qualität geführt hat. In den letzten Jahren kam es jedoch zu einer Reihe schwerwiegender Zwischenfälle in der Lebensmittelsicherheit, wie "Sudan red", "clenbuterol", "Sanlu toxic milk powder" und "trench oil". Es ist erwähnenswert, dass in den letzten 20 Jahren Skandale nicht nur in China, sondern auch in Europa, wie Beispielsweise Escherichia coli in Hamburgern, Salmonellen in Eiern, Geflügel und Schweinefleisch, Listeria in Pasteten und Käse oder etwa der "Pferdefleischskandal" 2013 zu beobachten waren. Diese Lebensmittelsicherheitsprobleme beeinträchtigen nicht nur die Gesundheit der Menschen, sondern untergraben auch ihr Vertrauen in die Lebensmittelmärkte.

Der Ansatz, der in dieser kumulativen Dissertation verfolgt wird ist es, zu versuchen die Lebensmittel-qualität und -sicherheit im Rahmen des Supply Chain Managements zu gewährleisten. Ziel ist es, ein Informationssystem zu bauen, das nicht auf das Vertrauen einer zentralen Behörde oder Organisation für die gesamte Lebensmittellieferkette angewiesen ist. Durch die Nutzung des Internets der Dinge und Blockchain-Technologien könnte dieses neue dezentrale Informationssystem zu einer bahnbrechenden Innovation werden, die allen Mitgliedern der Lieferkette (einschließlich Behörden und Aufsichtsbehörden) eine Informationsplattform auf der Grundlage von Offenheit, Transparenz, Neutralität, Zuverlässigkeit, und Sicherheit bietet. In dieser Forschungsarbeit wollen wir ein Rückverfolgbarkeitssystem für die Lebensmittelversorgungskette für die Echtzeitverfolgung von Lebensmitteln, und Sicherheitskontrollsystem für die Lebensmittelversorgungskette durch Integration von allgemeine Risikomanagementmethoden für Lieferketten schaffen, welches gleichsam die Leistung des Lebensmittellogistikunternehmens erheblich verbessert. All dies wird letztlich die Sicherheit einer Lebensmittelkette verbessern.

Abstract

With the rapid growth of China's economy, people's living standard has been increased continuously, which changed the consuming habit of consumers, and more and more attention is paid to food safety and quality. However, in recent years, a series of serious food safety incidents occurred, such as "Sudan red", "clenbuterol", "Sanlu toxic milk powder" and "trench oil". It is worth noting that not only in China, but even in Europe these kinds of scandals have broken out during the past 20 years, including Escherichia coli in hamburgers, Salmonella in eggs, poultry and pork, Listeria in pates and cheeses, and the "horse meat scandal" in 2013. These food safety problems not only harm people's health, but also undermine their trust in food markets.

The main purpose of this cumulative dissertation is trying to guarantee the food quality and safety from a supply chain management perspective, and the key issue is building a decentralized information system which is not dependent on the trust of a central authority or organization for the whole food supply chain. By using the internet of things and blockchain technologies, this new decentralized information system could become a disruptive innovation which could provide an information platform for all supply chain members (including government departments and third-party regulators) based on openness, transparency, neutrality, reliability and security. We want to establish a food supply chain traceability system for real-time food tracing, build a safety control system for food supply chain by integrating it with general supply chain risk management methods, and significantly improve the performance of the food logistics company. All of these will ultimately enhance the safety assurance of a food supply chain.

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1. Summarized introduction

Food safety concerns are drawing more and more attention. For instance, in recent years people have lost their confidence in China's food markets since a series of serious food safety events occurred. Therefore, in this cumulative dissertation we will delve into the food safety area from a supply chain management perspective.

In this cumulative dissertation we focused on establishing a new decentralized information system for food supply chain management by using the blockchain technology. Furthermore, we demonstrated how to apply this information system in the food safety area from a supply chain management perspective. As a first step, we established a safety control system for the food supply chain by integrating our new information system with the general supply chain risk management method HACCP (Hazard Analysis and Critical Control Points). This control system connects all the potential hazard points along the food supply chain, and implements information collecting, transferring, storing, checking, and sharing among supply chain members in order to enhance the quality and safety of the food products.

Then we designed a food supply chain traceability system in order to realize the traceability with trusted information in the entire food supply chain and effectively guarantee the food safety by gathering, transferring and sharing authentic data of food products in production, processing, warehousing and distribution.

Finally, the logistics capability of the cold-chain logistics enterprise could influence the quality and safety of food products directly. Therefore, discussed how this new information system could improve the performance of a cold-chain logistics enterprise, and demonstrated a performance evaluation research for a Chinese agri-food cold-chain logistics enterprise by using improved Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation methods.

We hope that our research could provide some ideas, methods and management suggestions from a supply chain management perspective for improving the quality and safety of food products, especially in China.

The related sub-topics of this dissertation are as follows:

The first paper: "A Quality and Safety Control System for China's Dairy Supply Chain Based on HACCP & GS1"[1]. In this paper, we propose a quality and safety control system of the dairy supply chain based on the combination of HACCP (Hazard Analysis and Critical Control Points) and GS1. By using GS1, this system could connect all the HACCP points along the dairy supply chain, and implement information collecting, transferring, storing, checking, and sharing among the supply members, which could effectively improve the supply chain efficiency, and guarantee the quality and safety of dairy products.

The second paper:"An Agri-food Supply Chain Traceability System for China Based on RFID & Blockchain Technology"[2]. This paper tries to build a new traceability system for agri-food supply chain by using RFID (Radio-Frequency IDentification) and blockchain technology which could realize the traceability with trusted information in the entire agri-food supply chain. This could effectively guarantee the food safety and improve the efficiency of the agri-food supply chain management.

The third paper: "A Supply Chain Traceability System for Food Safety Based on HACCP, Blockchain & Internet of Things"[3]. In this paper, we build a food supply chain traceability system for real-time food tracing based on HACCP, blockchain technology and Internet of things, which could provide an information platform for all the supply chain members with openness, transparency, neutrality, reliability and security. Furthermore, we introduce a new concept BigchainDB to fill the gap in the decentralized systems at scale. The paper concludes with a description of a use case and the challenges to adopt blockchain technology in the future food supply chain traceability systems are discussed.

The fourth paper: "Evaluation Research on Performance of Chinese Agri-Food Cold-Chain Logistics Company"[4]. This paper aims to build a performance evaluation system for the cold-chain company based on the Chinese agri-food industry to analyze its strengths

[1]This paper was presented in conference and published in proceeding: IEEE 2016 13th International Conference on Service Systems and Service Management (ICSSSM 2016), 24-26 June, 2016, Kunming, China. It is indexed by EI and published by IEEE Press. ISBN: 978-1-5090-2842-9.

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[3]This paper was presented in conference and published in proceeding: IEEE 2017 14th International Conference on Service Systems and Service Management (ICSSSM 2017), 16-18 June, 2017, Dalian, China. It is indexed by EI and published by IEEE Press. ISBN: 978-1-5090-6370-3.

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and weaknesses for improving its competitiveness. The proposed performance evaluation index system can assist managers to comprehensive comprehend the strengths and weaknesses of their agri-food cold-chain companies and could continuously improve the relevant cold-chain performance factors from the practice.

The final system which we build is a food supply chain traceability system for real-time food tracing based on HACCP, blockchain technology and Internet of things. This system could provide an information platform for all the supply chain members with openness, transparency, neutrality, reliability and security. Further more, it also fills the gap in the decentralized systems at scale issues by integrated the concept of BigchainDB. We believe that this system can extremely enhance the food safety and improve the efficiency of the food supply chain management in the real business environment in the future.

2. Research background

With the rapid growth of China's economy, people's living standard has been increased continuously, which changed the consuming habit of consumers, and more and more attention is paid to food safety and quality. However, in recent years, a series of serious food safety incidents occurred, such as "Sudan red", "clenbuterol", "Sanlu toxic milk powder" and "trench oil" (Xiao et al., 2012) [1]. It is worth noting that not only in China, but even in Europe these kinds of scandals have broken out during the past 20 years, including Escherichia coli in hamburgers, Salmonella in eggs, poultry and pork, Listeria in pates and cheeses (Yapp et al., 2005) [2], and the "horse meat scandal" in 2013 (Boyacia et al., 2014) [3]. These food safety problems not only harm people's health, but also undermine their trust in food markets.

In our opinion, from a supply chain management perspective there are two main reasons for this phenomenon, especially in China. One is caused by poor food supply chain systems. Although they have been developing rapidly in recent years, generally speaking, China's food supply chain systems are still at the primary stage, and there are many problems, such as shortage of modern equipment and funds, low level of information application, disordered regulatory systems, and lack of monitor-able traceability systems. Due to these reasons, food safety events have occurred frequently and massively in China. The other reason is caused by the information systems, which are used in food supply chains for guaranteeing the quality and safety of the food products. The first and the most important problem is information credibility. Generally speaking, the validity of information relies on the trusting in a centralized unit of the system or a powerful third-party organization. Such a centralized information system was, until recently, the only conceivable way to achieve information transparency along a supply chain [4]. However, there is an information asymmetry between the organizations and the individuals. The “centralized organization” can become a vulnerable target for bribery or targeted hacking, and if, for example, the administrator can be bribed, the real and valid information can be tampered with, so that the whole system cannot be trusted anymore. This is exactly what is happening in China’s food markets, as exemplified by the Sanlu toxic milk powder scandal. Besides that, there are some other problems, such as incomplete and duplicate information, which can seriously reduce the efficiency of the food supply chain management.

The main purpose of this cumulative dissertation is trying to guarantee the food quality and safety from a supply chain management perspective, and the key issue is building a decentralized information system which is not dependent on the trust of a central authority or organization for the whole food supply chain. By using the internet of things and blockchain technologies, this new decentralized information system could become a disruptive innovation which could provide an information platform for all supply chain members (including government departments and third-party regulators) based on openness, transparency, neutrality, reliability and security. We want to establish a food supply chain traceability system for real-time food tracing, build a safety control system for food supply chain by integrating it with general supply chain risk management methods, and significantly improve the performance of the food logistics company. All of these will ultimately enhance the safety assurance of a food supply chain.

3. State of the field

The aim of this section is to provide a short overview over the existing literature in the research area, which includes several aspects: food supply chain management, food traceability management, internet of things technologies, supply chain risk management methods, blockchain technology, performance measurement system and evaluation methods. Besides, research gaps in the contemporary literature on these topics will be summarized, and relevant methods and technologies used in this research will be introduced as well.

3.1 General works on food supply chain management and food safety

Food quality and safety are always the key factor for food supply chain management. How to guarantee the quality and safety of the food has been widely studied in relevant areas. Sun (2009) [5] presented a development strategy for Chinese agri-food cold-chain based on a comparative study of the cold chain industry development status between China and foreign countries. Besides, Chan et al. (2006) [6] insisted that in order to enhance the performance of the whole cold chain there is a need to consider the factors with which the performance of the products, process and services can be evaluated. Agri-food is a special product, whose inherent character should also be taken into account during the performance evaluation process. Bogataj et al., (2005) [7] have researched the stability of the agri-food in the cold chain and discussed the factors which decrease the hygiene and quality of the perishables. For perishables, in order to guarantee the expected safety, quality and freshness requirementsequipment with guaranteed thermal characteristics, an appropriate information system and proper operating modes are needed (Manning et al., 2006) [8]. Li et al. (2006) [9] developed a dynamic planning method for an agri-food supply chain. This method attempts to minimize the losses of agri-food products while simultaneously maximizing the profits for agri-food supply chain members. By using an analytical model, they demonstrated that real-time product information which passes through the agri-food supply chain could be valuably used. Many other researchers have studied agri-food quality and safety. Trienekens & Zuurbier (2008) [10] insisted that government departments should respond to ensuring the quality and safety of agri-food products by setting legislation and regulations. In order to restore consumer confidence in the wake of scandals, many measures are also being taken, such as implementing production protocols, or applying information technology in supply chain management processes to guarantee the quality and safety control through the transparency of the agri-food supply chain management (Akkerman et al., 2010) [11].

Several researchers specifically considered food safety in dairy supply chains. Valeeva et al. (2005) [12] divided a dairy supply chain into 4 blocks: feed, farm, dairy processing, and consumer and focused on the analysis of two main groups of hazards: chemical and microbiological by using conjoint analysis. Their study shows that controlling the chemical hazards is more vital for the feed and farm blocks; while controlling the microbiological hazards is considered more vital for the farm and dairy processing blocks. In order to improve the Chinese food safety record after the China melamine milk scandal, Pei et al. (2011) [13] made a comparative benchmark study of the Chinese and Austrian dairy sectors covering regulatory issues, official controls, and private standards. Kumar et al. (2011) [14] presented a case study to identify the determinants of compliance of food safety measures in dairy supply chain in India. Their study indicates that the adoption intensity of products safety practices is influenced by the characteristics of the dairy farmers, such as herd size, education level, and specialized knowledge in dairying. Moreover, highly integrated dairy farmers with a modern dairy supply chain have a positive impact on the adoption intensity of products safety practices at the farm level. Chen et al. (2014) [15] developed an analytical model and performed case studies to investigate the milk scandal in China. With this model, quality control is quantitatively analyzed in a centralized and decentralized supply chain and the impacts of pricing and regulatory policies on the quality and profit of the product are explored in their case studies.

3.2 HACCP method and food supply chain management

3.2.1 Introduction of the HACCP method

Hazard Analysis and Critical Control Points (HACCP) has been applied as an effective and rational method for guaranteeing food quality and safety “from farm to fork”. It can be used to comprehensively analyze various potential hazard factors which could cause food contamination for the entire dairy supply chain. HACCP was originally developed as a microbiologic safety system to assure food safety for astronauts by NASA in the 1960s (Bardic, 2001) [16]. Rather than other old food safety control systems which mainly rely on feedback control which is an inefficient approach and could result in huge loss, HACCP is a preventative method which could efficiently improve the level of food quality and safety (Bennet& Steed, 1999) [17]. Thanks to this approach, critical control points which contain hazardous factors can be effectively controlled, and thus achieve the aim of eliminating or reducing the food safety hazard to an acceptable level (El-Hofi et al., 2010) [18]. As a systematic preventive approach for food safety, HACCP has been widely used around the world, and in some countries and international organizations its usage is even enforced by law.

3.2.2 Literature review of the HACCP and food supply chain management

HACCP has been utilized in solving many safety problems in food supply chains. Henson & Holt (2000) [19] explored four key factors, namely, internal efficiency, commercial pressure, external requirements, and good practice, which could motivate the using of food safety controls by businesses through a study of HACCP adoption in the U.K. dairy processing sector. Their research results show that there are systematic differences in the HACCP adoption process between companies. Sperber (2005) [20] pointed out the lack of definitive critical control points which could hamper the effective application of HACCP in the entire supply chain. And we must focus on the application of effective food safety control measures rather than the critical control points from a HACCP system. Papademas & Bintsis (2010) [21] conducted a comprehensive literature review on food safety management systems in the dairy industry. They focus on the HACCP and relevant EC (European Community) regulation which are implemented by the dairy industry. Since a food cold-chain is very vulnerable to suffer from safety hazards, a risk assessment principle is badly needed to ensure the safety of the cold-chain. By using HACCP, Zhang & Chen (2011) [22] analyze all steps of a cold-chain, assess the potential risks, identify the CCPs, and give the relevant risk weights, so as to implement an entire risk assessment system for guaranteeing the safety of a cold-chain. In order to obtain high quality milk, Vilar et al. (2012) [23] implemented HACCP method on dairy supply chain, and they focus on the milk equipment and cooling tanks which could influence the milk quality by the hazards such as microbiological and chemical residues. They proved that implementation of HACCP can be a feasible strategy for dairy supply chain safety. Based on a Pareto analysis, Fotopoulos et al. (2011) [24] examined the literature on the food safety assurance systems and recorded the vital critical factors which affect the implementation of HACCP. In their research, they analyzed 31 studies and identified totally 32 factors that could affect HACCP implementation. By using a case study, Herath & Henson (2010) [25] pointed out four barriers to HACCP implementation, including perceptions which HAPPC is of "questionable appropriateness" to the company, the scale of change required to achieve implementation, low priority given to enhancement of food safety controls, and financial constraints.

3.2.3 Research gaps in the current literature

From a food supply chain risk management methods perspective, several studies have considered the use of HACCP in food supply chain management. However, most of these studies only focused on the relevant standards, regulatory issues, government policies, and cost and benefits associated with the implementation and operation of HACCP in the food supply chain. The key issue that they have not touched is that HACCP can be used to analyze and control the hazards at each key point of the entire food supply chain. However, the information of each point of HACCP along the supply chain is isolated. Therefore, this key information should be connected along the whole dairy supply chain, and only in this way the quality and safety of food products can be effectively guaranteed. In our research, based on the analysis of potential hazards in China's food supply chain, we will integrate information technologies, the internet of things and the blockchain, into HACCP to build a safety control system. This system could connect every isolated HACCP point along the food supply chain, and realize the information collecting, storing, transferring, checking, and sharing among supply chain members in a transparent, secure, and trust-free environment.

3.3 Internet of things and food traceability management

3.3.1 Introduction of the internet of things

The internet of things is an information network which connects all the things with the internet through information technologies like RFID, WSN, GPS and GIS, etc., in order to realize intelligent recognition and management. It is composed of sensor networks, information processing, high-speed and reliable public network, etc [26]. As the key technology of the internet of things, RFID has been widely applied. It is a non-contact automatic identification communication technology, which can automatically identify multiple, high-speed moving objects simultaneously even under poor environment and without manual intervention. Moreover, it can tag, save and manage information of objects through a radio-frequency signal. Compared to bar codes, RFID tag technology has a lot of advantages, such as convenience, antipollution, mass-capacity information capability and recyclability.

In the logistics area, RFID has been widely used in production, warehouse management, logistics tracing and product anti-fake measures, etc. Over the years, more and more attention has been paid to the development and application of RFID in many countries. As the leader of RFID technology, from setting the standards to the development of relevant software and hardware, the USA is more advanced than other countries. The RFID standard of the EU is just following the American EPC global standard, and in the application area they are basically at the same developmental stage. Furthermore, relying on domestic enterprises, Japan established a UID (Ubiquitous ID) standard. The development of Chinese RFID technology started relatively late, but it developed very fast in recent years and has been extensively applied in many areas, such as logistics, catering, retailing, manufacturing, medical treatment, identification and payments.

3.3.2 Literature review of the internet of things and food traceability management

Many researchers considered the application of the internet of things technologies, including RFID (Radio-Frequency Identification), WSN (Wireless Sensor Network), GPS (Global Positioning System) and GIS (Geographic Information System), etc., in supply chain management. Sari (2010) [27] developed a simulation model to find out under what conditions investing in RFID technology is beneficial for the firm. The study results show that using RFID technology in a supply chain will provide more benefits when the collaboration among supply chain members is more intensive, and these benefits are greater when the lead-time is longer and demand uncertainty is lower. Ustundaga& Tanyasb (2009) [28] presented a simulation model to obtain the expected profits of using a RFID-based system in a supply chain by calculating the performance increase in efficiency, security, accuracy and visibility. Their study shows how product value, lead-time and demand uncertainty of the market influence the performance of the RFID system in the supply chain.

Several researchers tried to apply these information technologies in food supply chain management in many different ways. Wang et al. (2010) [29] proposed a rule-based decision support system to fulfill the real-time monitoring of agri-food products during their distribution process. Based on information transmitted by sensor-RFID equipment from refrigerated containers, this system calculates the remaining value and shelf-life time of agri-food products in transmission. Based on the concept that data must be gathered, stored and shared in each link of the supply chain, Manikas & Manos (2009) [30] developed a model which realizes traceability in the food supply chain. This model consists of three steps, natural environment, transformation, and distribution, which represent the stages of real-life supply chains. They insisted that this model could be the basis for the development of a web application for traceability management in a dairy supply chain. Grunow & Piramuthu (2013) [31] developed a model and studied the application of RFID technology in a highly perishable food supply chain from the perspectives of the distributor, retailer, and customer. In their model they found that the investment in the application of RFID technology could benefit the distributor, retailer, and customer when facing the issue of remaining shelf-life in the food supply chain. Cao et al. (2014) [32] built a general framework for animal food safety traceability by using RFID tags encoded with EPCglobal tag data standards. In this framework, the discovery service and the object name service are used to locate dynamic distributed information servers for dynamic data sharing. Since most agri-foods are very perishable and their shelf-life time can be seriously influenced by temperature and humidity in logistics processes, refrigerated containers which are used to transport agri-food products could affect quality and safety to a large extent (Montanari, 2008) [33]. Jedermann& Lang (2009) [34] developed the spatial temperature profile in refrigerated trucks and containers, which rely on RFID and sensor technology to automatically record and transfer the information of the transport environment (e.g., temperature, humidity) in the distribution process. Several available tracking and tracing technologies for this application are also evaluated and compared in their study.

Food traceability management has drawn more and more attention in research. It is defined by the European Union Commission as “the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution” (European Commission, 2002) [35]. Golanet al. (2004) [36] established a tracking and traceability system by using RFID technology to effectively monitor the key information of the whole food supply chain. Once there is an accident happening, the relevant questions can be immediately traced and tracked, which could ensure the food quality and safety. Aimed at the needs of the tracking and traceability in supply chain management, Li et al. (2010) [37] proposed a RFID-based logistics tracking and tracing model, and defined five different kinds of RFID business events. Besides, they also design the network structure, functional framework and security systems of the logistics tracking and tracing system. Taking agri-food as research object, Yang et al. (2008) [38] built a security management and quality traceability system of vegetable production from the perspective of information technology, and demonstrate its main functions, operational processes and key technologies.

3.3.3 Research gaps in the current literature

On the information technologies and systems side, the literature on using internet of things technologies in food supply chain management is very rich. However, the first and the most important issue that isnot touched is that whether the information shared by food supply chain members in the traceability systems can be trusted. The novel technology that allows this is the blockchain, and based on this technology and the internet of things we could establish an information system that is not dependent on the trust of a central authority. Instead of storing data in an opaque information system, with the blockchain technology all information of the food products can be stored in a shared and transparent system for all the members along the supply chain. Furthermore, there is no published paper which proposes the using of the blockchain technology to solve the issue of information credibility in food supply chain traceability systems. Secondly, instead of covering all stages of the food supply chain management, most studies only focus on some relatively independent steps, such as distribution, warehousing and refrigeration. Therefore, in our research a new food supply chain traceability system will be developed by using the internet of things and the blockchain technologies. Besides, the details of its implementation process in every supply chain link will be demonstrated. This new system could effectively improve the efficiency and reliability of the food supply chain management, and significantly strengthen the quality and safety of food products.

We will simply describe our new system by compare it with centralized system which is, to date, widely used in food supply chains. In a centralized food supply chain, supply chain members rely on an information supervision center to transfer and share their information. It can effectively implement the information sharing and, to some extent, realize the traceability management in the whole food supply chain. However the biggest problem of this centralized format is that it is a monopolistic, asymmetric and opaque information system, which could result in the trust problem. Our new traceability system which applies blockchain technology could obviously solve this issue. First of all, it relies on internet of things to implement data acquisition, circulation and sharing in production, processing, warehousing, distribution and sales links of food supply chain without any so-called supervision center. Secondly, and most important, it uses blockchain technology for guaranteeing the information which shared and published in this system is reliable and authentic. Therefore, instead of being an information supervision center, government departments and third-party regulators are just some normal nodes of the system, like all the other members. Thanks to blockchain technology, our new system could become a disruptive innovation which could increase the transparency of the supply chain, strengthen the information credibility, realize the real-time tracking, and consequently, enhance the safety assurance of the food supply chain.

3.4 Blockchain technology

3.4.1 Introduction of the blockchain technology

The essence of the blockchain is a technical scheme of a reliable database which is collectively maintained via a decentralized and trustless method. This technical scheme creates blocks through any number of nodes in the system by using cryptography. It is just like what the name says: a chain of blocks. Each block contains the data of all transactions in the system within a period of time, and it creates digital fingerprinting which can be used to verify the validity of the information and connect with the next block [39]. There can be a huge number of such blocks in the blockchain. The blocks are linked to each other like a chain in a linear , chronological order with every block containing a hash of the previous block.

The blockchain technology can be visualized as a general term for technical schemes which are similar to NoSQL (Not Only Structured Query Language) databases, and it can be realized by many kinds of programming languages. Currently, there are some methods for achieving that, such as POW (Proof of Work), POS (Proof of Stake) and DPOS (Delegate Proof of Stake).

According to the definition of the blockchain above, a blockchain-based system should be decentralized, trustless, collectively maintainable, reliable and anonymous.

Decentralized: there is no central organization in the whole network, and even if a node crashes, the whole system will still be up. Therefore, the blockchain system is very robust.

Trustless: since the whole system is running transparently, the system is absolutely open source and there is no need for trust among every single node and any node can never cheat other nodes.

Collectively Maintainable: the blocks of the system are maintained by all the nodes in the whole system, and everyone can become a node of the system after registering online.

Reliable: every node could receive a complete copy of the database from the system through the form of sub-database. Tampering with the database by one node is invalid, and that could not influence the data of other nodes, unless one can control over 51% of the nodes in the whole system at the same time. Thus, if there are more nodes in the system, it will be more secure.

Anonymous: since there is no need for trust between nodes, there is no need for nodes to reveal their identities and all the nodes in the system are anonymous.

The core problem solved by the blockchain technology is how to create a trust-free environment for business and management activities in the situation of information asymmetry. This problem is known as “Byzantine failures”: how we can build a consensus foundation for secure information transactions without worrying about data tampered when any nodes cannot be trusted in the whole network. The blockchain can guarantee the security of the whole network by using a mathematical algorithm mechanism [4]. Thanks to the blockchain, all the nodes in the system can exchange their data autonomously and securely in a trustless environment.

Blockchain can be seen as a distributed database or ledger: a chronological chain of blocks and each block stores all information of network activity since the block is added to the chain [40]. All the data in the blockchain is public, and any user can add data to it in the form of a transaction which is identifiable data package in the system, any user can check and copy this data at any time, but it is prohibitively expensive to change it. Therefore, blockchain is an immutable history of network, which can be shared among all nodes on this distributed network. And the key feature of the blockchain-based system is that it removes the need for any centralized trust authority. Instead, trust is achieved through a so-called mining process which guarantees the security and validity of the information added to the chain among the nodes within the system.

In the mining process (voting process), new transactions are verified by the nodes in the whole system known as “miners” before being added to blockchain. Miners add new blocks on the chain or new transactions on the block by a consensus algorithm, which must be confirmed by majority or all the nodes in the system, like a voting operation, as the valid data. Blockchain-based systems rely on miners to aggregate transactions into blocks and append them to the blockchain. Once the transaction is confirmed by a sufficient number of nodes, it becomes a valid and permanent part of the database [41]. In order to constantly validate and maintain the consistency data, the system rewards the miner for adding valid blocks to the chain by some form of digital credit like “gas” which is used to discourage over-consumption resources (During the execution of a transaction, every program instruction will consume some gas. Therefore, the user must pay some money for it). In this system, no single miner can change or add invalid data without being detected by other miners as a “bad actor”. Moreover, the miner can not receive the reward if the relevant block is rejected. This method significantly enhances the transparency, trust, and traceability in a system.

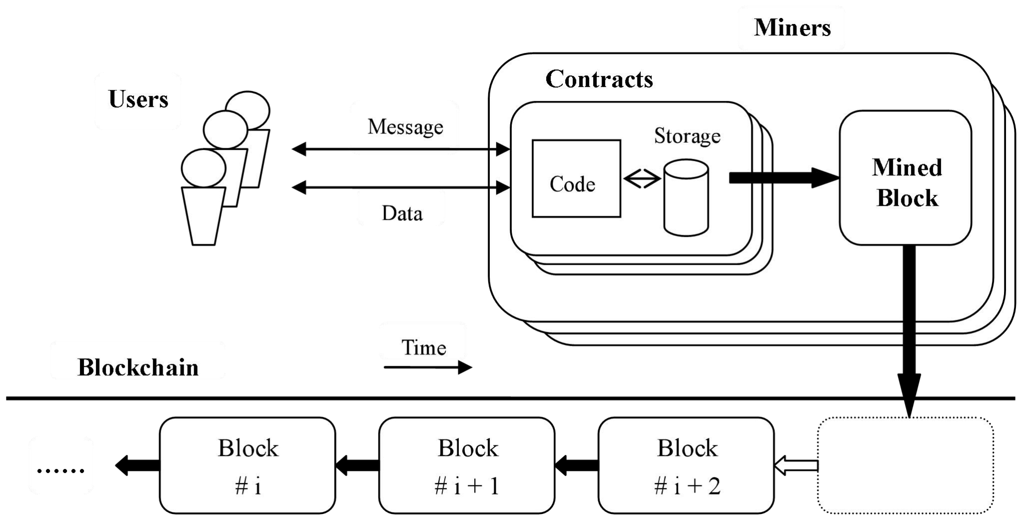

Fig. 1. Conceptual framework of a blockchain-based system with smart contracts

A smart contract is a computer program that runs on the blockchain, i.e., executed by all consensus nodes. It consists of program code, a storage file. Any user can create a contract by posting a transaction to the blockchain. The program code of a contract is fixed when the contract is created, and can not be changed [42]. As shown in Fig. 1, the storage file of the smart contract is stored on the blockchain. Its program logic is executed by miners who reach a consensus on the outcome of the execution and update the blockchain accordingly. The code of the contract can be executed when it receives a message. The smart contract can read from or write to its storage file, while executing its code. Actually, the entire state of a smart contract is open to all the users in the system.

3.4.2 How blockchain works

In this section, we will demonstrate the voting process of the blockchain, which can explain how blockchain works in our BigchainDB system.

As is shown in Fig. 2, there are two distributed databases: a transaction set called "backlog" which can insert and assign incoming transactions, and a blockchain which will store ordered transactions. The registered user (node) in this network system can update "backlog", blockchain, and transactions between them by voting process based on a Consensus Algorithm.

The voting process can decide whether the block is valid or invalid. In this process, registered nodes will check all the transactions of the block, and if any invalid transaction has been found, and then they will vote this block is invalid. Once there is a majority (over 50%) of valid votes or invalid votes for a block, the block will be decided valid or invalid, and the result can never be changed.

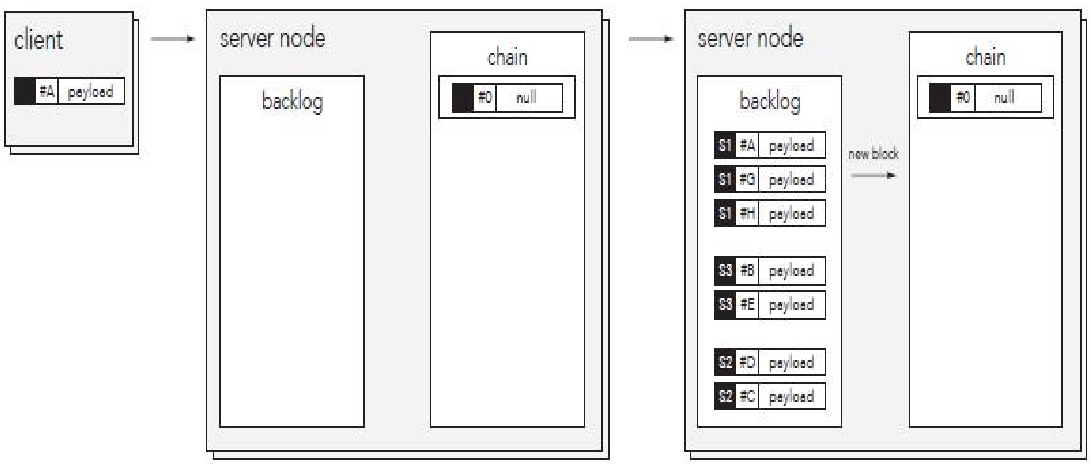

Fig. 2. Voting Process (1). Left: backlog and chain start empty except for a genesis block with a null transaction; Right: client has inserted transactions into backlog and assigned to nodes 1,2, and 3. (Source: author with reference to McConaghy et al. (2016)) [43]

When a registered node sends a transaction, it will be assigned to one of the registered node in the system, and be stored in the backlog. As we can see in Fig. 2 right, three transaction are assigned to node 1: #A, #G, and #H; two transactions are assigned to node 2: #D and #C; two transactions are assigned to node 3: #B and #E.

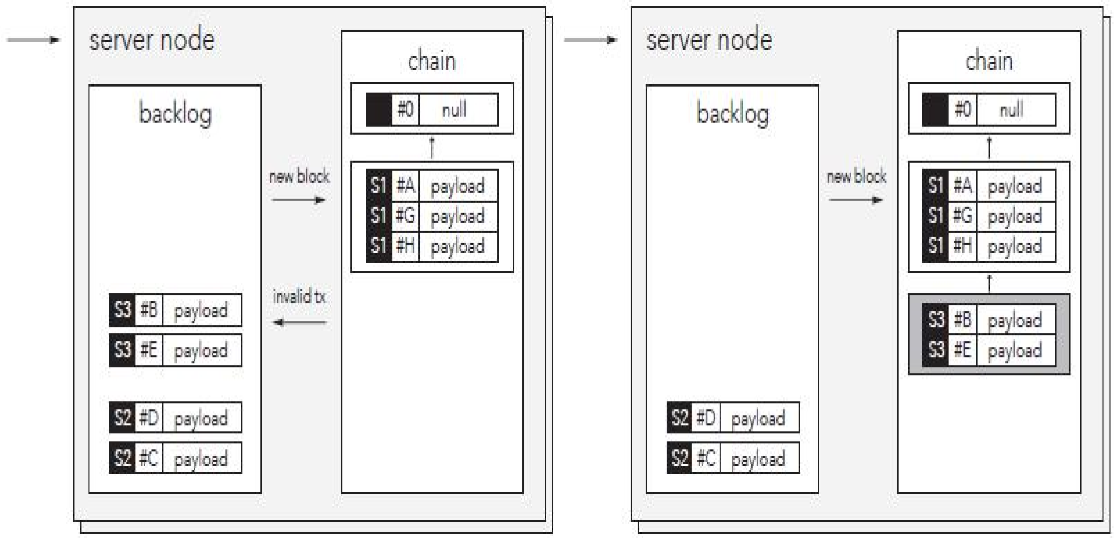

Fig. 3. Voting Process (2) (Source: author with reference to McConaghy et al. (2016)) [43]

As is shown in Fig. 3 left, node 1 has transfered the transaction #A, #G, and #H from backlog to chain as a new block which links to the previous block. And in the Fig. 3 right, we can see that node 3 also transferred all of its transactions to chain as a new block. When these new blocks are inserted on chain, each server node (registered node) may vote for them. According to the voting result, the block changes from undecided to valid or invalid.

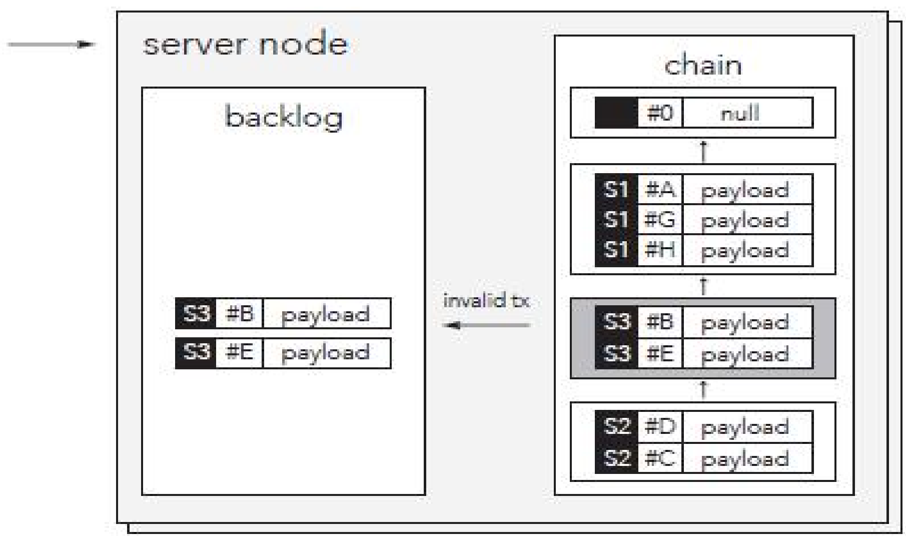

Fig. 4. Voting process (3) (Source: author with reference to McConaghy et al. (2016)) [43]

In Fig. 4 we can see that the blocks created by node 1 and 2 are valid, while, the block created by node 3 is invalid. We can also find that the transactions from the invalid block are re-inserted into the backlog for re-consideration.

3.4.3 Scalability of the blockchain

The features of blockchain include “decentralized control”: no single entity can control the whole network; immutability: written data can never be tampered with; and “the ability to create & transfer assets”: remove the need for a central entity. These features can improve the security and transparency of decentralized systems. However, blockchain technology has scalability issues in terms of throughput, latency, and capacity when faces mass data in a real business environment.

As is shown in Table 1, McConaghy et al. (2016) [43] proposed the concept of BigchainDB, which combines the key benefits of distributed DBs and blockchains.

Table 1. Key characteristics of Blockchain, Distributed DBs & BigchainDB

	Blockchains	Distributed DBs	BigchainDB
High throughput	-	√	√
Low latency	-	√	√
High capacity	-	√	√
Decentralized control	√	-	√
Immutability	√	-	√
Creation & movement of digital assets	√	-	√

3.4.4 Literature review of the blockchain technology

Currently, a new technology called blockchain has drawn much attention from researchers in many different domains. The first application of the blockchain technology was Bitcoin, a peer-to-peer electronic cash system [44]. Beyond its initial application, blockchain has been generalized and researched in some different domains. Kosba et al. (2015) [45] presented a decentralized smart contract system: Hawk. Unlike other existing decentralized block chain systems in which all the transactions are exposed clearly on the block chain, “hawk” does not store financial transactions on the block chain, thus retaining transactional privacy from the public’s view. Bruce (2013) [39] proposed a purely P2P crypto-currency scheme with the “mini-blockchain”. In their research they defined the “mini-blockchain”, “proof chain” and “account tree”, and described how these three mechanisms work together to build a system that can provide a high level of integrity and security, yet was much slimmer than all other purely P2P currencies. Beyond that, this system also has many other advantages such as faster transactions and lower fees, quicker network synchronization, support for high levels of traffic, more block space for custom messages, and increased anonymity. Foroglou et al. (2014) [44] introduced the blockchain technology and the background of Bitcoin. Furthermore, they showed how blockchain technology can be advantageously used in different domains, such as the currency, contracts, voting, intellectual property rights, smart property and finance, in the future. Abeyratne & Monfared (2016) [41] discussed the potential benefit of blockchain technology in manufacturing supply chain. They proposed that the inherited characteristics of the blockchain enhance trust through transparency and traceability within any transaction of data, goods, and financial resources. And it could offer an innovative platform for new decentralized and transparent transaction mechanism in industries and business. In addition, they also take manufacturing of cardboard boxes as an example to demonstrate how blockchain technology can be used in a global supply chain networks. As the lack of trust is a barrier for integration of business process across organizations, Weber et al. (2016) [46] insisted that blockchain could be an emerging technology for decentralized and transactional data sharing across a network of untrusted participants. They developed a technique to integrate blockchain into the choreography of processes in such a way that no central authority is needed, but trust maintained. Among these researches, some other researchers tried to solve the shortcomings, especially scalability, of blockchain. McConaghy et al. (2016) [43] described BigchainDB, which combine the distributed database (DB) with blockchain characteristics. Therefore, it has characteristics of distributed databases: linear scaling in throughput and capacity, efficient querying, and permissioning. And blockchain characteristics: decentralized, immutability, and creation & movement of digital assets. Croman et al. (2016) [47] analyzed fundamental and circumstantial bottlenecks of the blockchain for supporting substantially higher throughputs and lower latencies. Their results suggested that block size and intervals should be viewed only as a first increment toward achieving the next generation. In order to realize scalability, they discussed the techniques of blockchains from five planes, ordered in a hierarchy of dependency from bottom to top, Network, Consensus, Storage, View, and Side Planes.

An application of blockchain technology consists of a number of smart contracts. A smart contract is an instance of a computer program that runs on the blockchain, i.e., executed by all consensus nodes. It consists of program code, a storage file, and an account balance. Any user can create a contract by posting a transaction to the blockchain. The program code of a contract is fixed when the contract is created, and can not be changed [42]. The smart contract has been widely used in the financial and virtual currency sector. For example, it can be used for betting purposes playing the role of the notary as the need for a carrier that controls the bets does not longer exists. The users put their money on a digital account, they create a virtual contract that define the conditions of winning and losing and when a result came up in the real word, the contract get updated from an online database and execute the terms by transferring the money to winner's account [44]. However, as an emerging technology, blockchain is still in its initial phase and there are some obstacles to its application. For instance, right now the transaction capacity of the blockchain is restricted to 7 transactions per second [39], while sensor data is transferred continuously on a massive scale.

3.4.5 Research gaps in the current literature

According to the discussion above, many researches have considered the possibility of using blockchain technology in many domains for its advantages and characteristics. However, there is no published paper that proposes adopting blockchain technology for improving food safety in supply chain management areas. In this research, a decentralized information system is developed based on HACCP, blockchain and internet of things for food supply chain monitoring and traceability. Compare to the centralized systems, this new system could become a disruptive innovation which provides an information platform for all the supply chain members with openness, transparency, neutrality, reliability and security. Moreover, we also discussed the scalability of the blockchain technology when processing massive data within a business environment. We believe that our system could be a new perspective and idea for supply chain monitoring and traceability, and significantly enhance food safety in food supply chains.

3.5 Performance evaluation methods and supply chain management

3.5.1 Introduction of the Improved AHP and fuzzy comprehensive evaluation methods

AHP is utilized in solving multi-criterion decision-making (MCDM) problems. Such kinds of problems can be solved analytically when all the parameters are quantitative (Wang et al., 2011) [48]. However, many evaluation criteria are qualitative in nature. With AHP one can set up a hierarchy of criteria and sub-criteria, which can be either quantitative or qualitative in nature,and pair-wise comparisons between the criteria evaluated by experts in the relevant area can be performed. Unfortunately, AHP is unable to deal with uncertain and ambiguous variables (Wang et al., 2008) [49].Though the purpose of AHP is to capture the expert's knowledge, is still can not reflect the human thinking style. Furthermore, fuzzyness and vagueness are characteristics of many decision-making problems. For example, decision makers usually find that it is more confident to give interval judgments than fixed value judgments [50]. In order to address this deficiency, fuzzy AHP which blends AHP with fuzzy comprehensive evaluation has been developed and used in solving many industrial problems. This method was first introduced by Van laarhoven and Pedrycz (1983) [51]. Güngör et al., (2009) [52] utilized fuzzy AHP to rank the performance of different applicants for human resources selection. In this research, an improved AHP will be used to determine the index weights, which is a fundamental solution to the problems of the matrix consistency test. This method could not only reduce the workload of the repeated re-construct the judgment matrix, but also insure the consistency of the comparison matrix, which could simplify the process of index weights determination (Liu et al., 2012) [53].

3.5.2 Literature review of performance evaluation methods and supply chain management

Many researchers (Joshi et al., 2011; Ghobadian et al., 2007; Gunasekaran et al., 2004; Otto & Kotzab, 2003) [54-57] have greatly contributed on PMS for the supply chain management. A few studies have been done on the agri-food supply chain management. Li & Zu (2007) [58] incorporated social responsibility into the balanced scored card (BSC) and constructed a performance evaluation index system for a logistics company covering five aspects: finance, customer, internal process, learning & development, and social responsibility. Building a performance evaluation system of a cold-chain is complex, because it has many special characteristics like long production throughput time, large investment, refrigerated transportation and storage requirement, product quality and safety, etc. (Aramyan et al., 2007) [59]. Table. 2 shows the common comprehensive evaluation methods.

Table 2. Common comprehensive evaluation methods

Name	Advantage	Disadvantage	Main application
Fuzzy comprehensive evaluation method	By using fuzzy logic, it could obtain the result of multilayer problem. And it has great expandability.	Information overlapped among the indexes can not be solved; the determination process of membership degree function & relevant fuzzy matrix need to be further investigated.	Performance evaluation, competitiveness evaluation, & technological innovative ability evaluation of the company.
BP artificial neural network evaluation method	Dealing with the complex systematic problem, such as non-linear, non-locality problems.	Low precision, and need huge number of samples.	Comprehensive assessment for the development level of the city.
Factor analysis method	Comprehensiveness, objectivity & comparability.	Need huge number of samples; sometimes can not accurately reflect objective reality.	Customer satisfaction, customer purchasing, & market segmentation analysis.
Grey connecting degree synthetic evaluation method	It could be used for gray system; demanded for information is not large; can be used for dealing with the systems which have a high correlation.	The determination of time variables is very difficult; comparable variables should be chosen.	Evaluation for economic benefits, competitiveness & development level.

Improved three scale AHP	It applies to multi-hierarchy structure systems & the comparison of relative quantity; has high reliability & minor error.	Selective restriction of the evaluation objects	Resource allocation problem; cost-benefit decision; conflict analysis.
Relevant matrix method	It can be easily applied to determine the weights of evaluation objects & values of alternative solutions.	Can be only used for static evaluation.	Safety evaluation for transportation system; development plan for new products.
Linear weighted sum method	It could be used to accurately describe evaluation objects and deal with multi-index dynamic comprehensive evaluation system.	Scope of application is limited; can not be used for fuzzy evaluation.	Evaluation & decision for optimizing system.

3.5.3 Research gaps in the current literature

On the performance evaluation methods side few efforts have been made for constructing a performance evaluation system for food supply chains, especially for cold-chains. Besides, there is no performance evaluation system in the food cold-chain area which uses the improved fuzzy AHP combining both qualitative and quantitative factors into the evaluation system. In our research, a performance evaluation system will be developed for evaluating the performance of agri-food cold-chain enterprises. Moreover, based on a case study of a agri-food cold-chain logistics enterprise, we will discuss the role of this information system in enhancing the performance of the cold-chain logistics enterprise, and we will also provide some management suggestion and methods for improving the logistics capability of the agri-food cold-chain logistics enterprises. Since our information system is the first such artifact that is applied in food supply chain management for food safety, we can only test it theoretically. But it can be a cumulative knowledge base for further research extensions.We believe that our research will not only enrich the literature in this field, but will also help the food logistics enterprises to improve their management and operation process, which will significantly enhance the quality and safety of food products, especially in China’s food markets.

4. Research questions

As mentioned above, the main aim of this research is trying to guarantee the food quality and safety from the supply chain management perspective, and according to the analysis of the literature above, we will achieve this aim from several perspectives. The first and key step is that we will try to establish a new decentralized information system based on the blockchain and internet of the things technologies. Relying on this information system we can solve the issue of information asymmetry and opacity in food supply chains. Secondly, we will integrate this information system with supply chain risk management methods (like HACCP) to build a safety control and traceability system for food supply chains. Finally, we will further discuss how this new system improves the performance of the food supply chain management, and we will also use the improved Fuzzy-AHP evaluation method to make a case study on a Chinese agri-food cold-chain logistics enterprise. In this way, we can find out how to enhance the food safety by improving the logistics capability of food logistics enterprises. In order to achieve our research purpose, we propose the following research questions in each sub-topics are as follows:

Table 3. Research questions of the dissertation

Research Questions
Topic 1: The third topic: A Quality and Safety Control System for China's Dairy Supply Chain Based on HACCP & GS1
1. What are the structural features of nowadays China's dairy supply chain? And what are the potential hazard factors in this dairy supply chain? 2. How to apply HACCP method in the dairy supply chain? 3. How to build a quality and safety control system based on the combination of HACCP method and GS1 for improving the quality and safety of dairy products?
Topic 2: An Agri-food Supply Chain Traceability System for China based on RFID & Blockchain Technology
1. What is blockchain technology? And how to use it in a supply chain traceability system? 2. What are the advantages & disadvantages of using RFID & blockchain technology in building an agri-food supply chain traceability system? 3. How does this new traceability system work in the whole agri-food supply chain?
Topic 3: A traceability system for China's dairy supply chain-based on a comparative study between Austria and China
1. How can the HACCP be used to identify the information needs of a food safety monitoring information system? 2. What methods of data capture and transmission are necessary to collect this information safely? How can misuse of the information in the blockchain and tempering with the input devices be prevented? 3. What architecture (smart contracts) are suitable for processing this information within a blockchain?
Topic 4: Evaluation Research on Performance of Chinese Agri-Food Cold-Chain Logistics Company
1. How to build a performance evaluation system for the cold-chain company to analyze its strengths and weaknesses for improving its competitiveness in agri-food quality and safety area? 2. How can we apply this performance evaluation system to evaluate the performance and ability of the agri-food cold-chain logistics companies? 3. According to the evaluation results, what kinds of management suggestions can we provide to improve the competitiveness of the target company, and furthermore, enhance the quality and safety of the agri-food in China's markets?

5. Design science and methodology

5.1 Problem relevance

Food safety concerns have drawn much attention from researchers in many different domains. In the supply chain management area, with the rapid growth of the internet of things, many kinds of information systems have been designed and applied for improving the safety of food products. However, all of these information systems are centralized systems which have many weaknesses. The biggest problem is that this kind of centralized system is a monopolistic, asymmetric and opaque information system, which could result in the trust problem, such as fraud, corruption, tampering and falsifying information. Besides that, there are some other problems, such as incomplete and duplicate information, which can seriously reduce the efficiency of the food supply chain management. Thanks to the internet of things and the blockchain technologies, these kinds of problems can be solved.

5.2 Research rigor

Research on information systems and food supply chain risk management areas has a long history of formal and rigorous results that have been applied to the design of many safety mechanisms to improve food safety. In this paper, by using the internet of things and blockchain technologies we will design a new decentralized information system, based on the literature review. By integrating such new information system with the food supply chain risk management method HACCP, we can develop a food safety control and traceability system for the whole food supply chain. Finally, we will describe how to test this system in a business environment by using improved AHP method to measure how it improves the management performance and food safety in the food supply chain. In summary, this research will apply the relevant literature in developing the artifact information system design document and, describe how to use the appropriate performance evaluation method to test the artifact within an appropriate context.

5.3 Design as a search process

As discussed above, designing an information system that is not dependent on the trust of a central authority is central to this research. By analyzing the weaknesses of a centralized information system, we will build a new decentralized information system based on the internet of things and the blockchain technologies. This new information system will provide an information platform for all the members providing openness, transparency, neutrality, reliability and security. Furthermore, relying on this new information system, we will integrate it with HACCP along food supply chain to establish a food safety control and traceability system, and test it within a business environment to measure how it improves the food safety and management performance of the food supply chain.

5.4 Design as an Artifact

The core artifact of this research is the design of a new decentralized information system based on the internet of things and the blockchain technologies. This new system removes the need for a trusted centralized organization and improves the information transparency of the food supply chain. Furthermore, rely on this system we can realize tracking and traceability management along the whole food supply chain.

Integrating this decentralized system with HACCP, we could obtain our complete artifact "a food safety control and traceability system". In this system, the quality relevant information of each object (food products, equipment, environment, and materials, etc.) in the food supply chain can be automatically sensed, sent, and identified by the internet of things, like RFID and WSN. However, this information is normally on a massive scale, and due to the weakness of the blockchain technologies, only the key information (transactions) of the object will be executed as a smart contract and added to the blockchain. For the rest of the normal information, such as details of the products, equipment, environment, and materials, it will be transferred and saved in a trustworthy party (government departments or third-party regulators) which is a normal node in the whole system, just like all the other members of the system.

Since each supply chain member has an account on the blockchain and a smart contract that stores all the messages of the object in the whole supply chain process, the resulting object history can be monitored and checked by all the supply chain members anytime. Moreover, alerts will be generated and relevant emergency measures and actions will be taken immediately in case of problems.

5.5 Design Evaluation

We will evaluate the food safety control and traceability system design in several important ways:

First of all, our design of a new decentralized food safety control and traceability system will be compared and contrasted with the centralized one which has been widely used in the food supply chain area for food safety supporting. As we mentioned above, this centralized information system could bring the trust problem and difficult to adapt to food safety management along the supply chain in the future.

Secondly, as the key technology of our new decentralized information system, the blockchain has been applied in some other business domains to solve information trust problems [44].

Finally, it will be shown how the improved fuzzy AHP method can be used to measure how this food safety control and traceability system could enhance food safety and improve the performance of the food supply chain management within a business environment.

5.6 Research Contributions

The most important design-science contribution of this research is the design of a new decentralized information system which is based on the internet of things and a novel information technology "blockchain". This new system could remove the need for a trusted centralized organization and provide an information platform for all the members with openness, transparency, neutrality, reliability and security. Furthermore, we will pose a food safety control and traceability system by combining our new decentralized system with HACCP. It could realize food tracing, improve the performance of food supply chain management, solve information trust problem, and significantly enhance the food safety in the food supply chain.

5.7 Research Communication

This research will provide clear information to both technical and managerial audiences. Recognizing that existing systems (centralized information systems) have their inherent defects for information sharing and security, we identify an opportunity to apply new information technology (blockchain) in an innovative way to establish a new system (decentralized information system). Since it is the first such artifact that is applied in food supply chain management for food safety, it can be a cumulative knowledge base for further research extensions. For instance, with the rapid development of these information technologies, this artifact can be further optimized. Moreover, if our artifact can be widely used in the business environment in the future, empirical studies and tests can be implemented more in depth. Managers should have a good understanding of the implications of the decentralized information system with food supply chain risk management. This understanding should include an appreciation of how critical control points among different steps of food supply chain can be supported by our new system, and how it improves the performance of food supply chain management and enhances the food safety. This research would be more accessible to a managerial audience if it included a stronger motivation up front on the important implications of our artifact in food safety and supply chain management areas.

6. Analysis and results

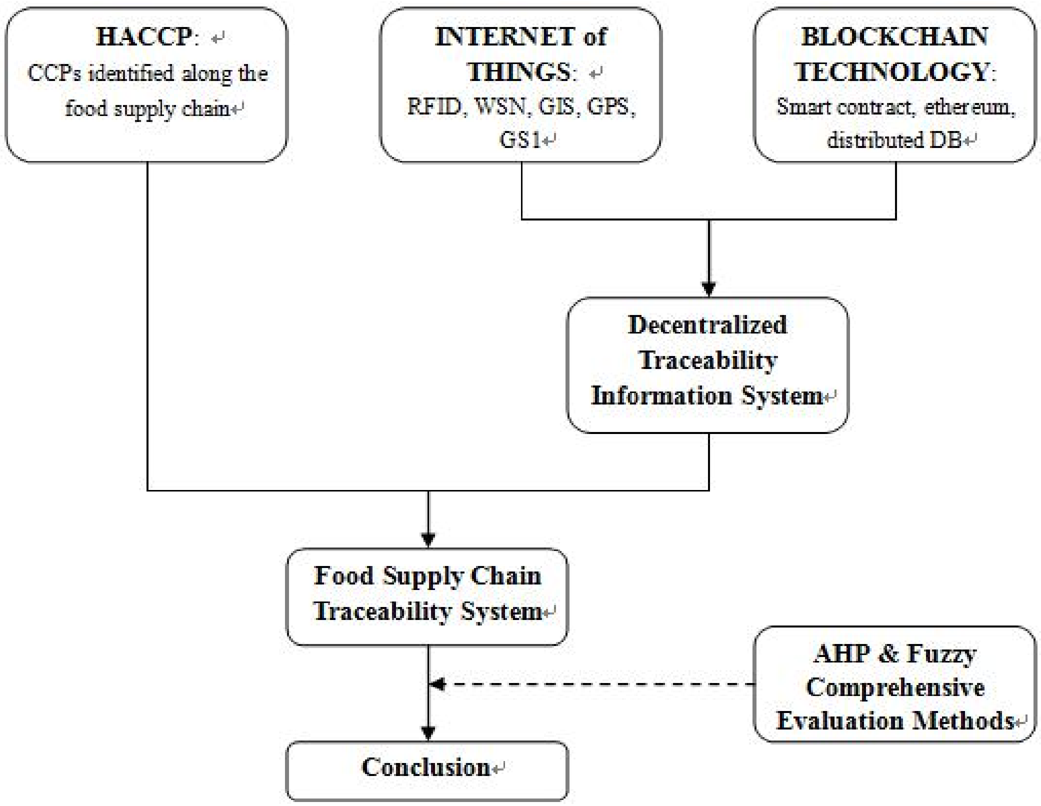

Fig. 5. Basic logical structure of the whole research

The main purpose of this research is to guarantee the food quality and safety from the supply chain management perspective. Fig. 5 shows the basic logical structure of the whole research. It is expected that the existing publications in this research area will be summarized thoroughly to shed light on research on food safety and supply chain management fields in the future. Besides, the literature review in this research will examine currently existing researches, identify research gaps and address directions for further researches. Furthermore, as we discussed above, our research will not only propose a new way for food safety management, but also improve the performance of the relevant food supply chain management activities. Therefore, this research will extend the knowledge for both researchers and management practitioners on the application of information technologies in food supply chains, food supply chain traceability management, food supply chain risk control management, and evaluation research on the performance of food supply chains. We believe that this will greatly improve the quality and safety of the food products in the future. The main purpose of this cumulative dissertation could be divided into several expected results in the following papers:

6.1 The first paper: A Quality and Safety Control System for China's Dairy Supply Chain Based on HACCP & GS1

First of all, this paper presented the development status of China's dairy supply chain and relevant quality and safety problems of dairy products. In addition, we analyzed the structural features of nowadays China's dairy supply chain.

Secondly, we demonstrated the application of the HACCP method in diary supply chain, and analyzed the potential hazards along the whole dairy supply chain of nowadays China's market. Fig. 6 shows the determination process for CCPs.

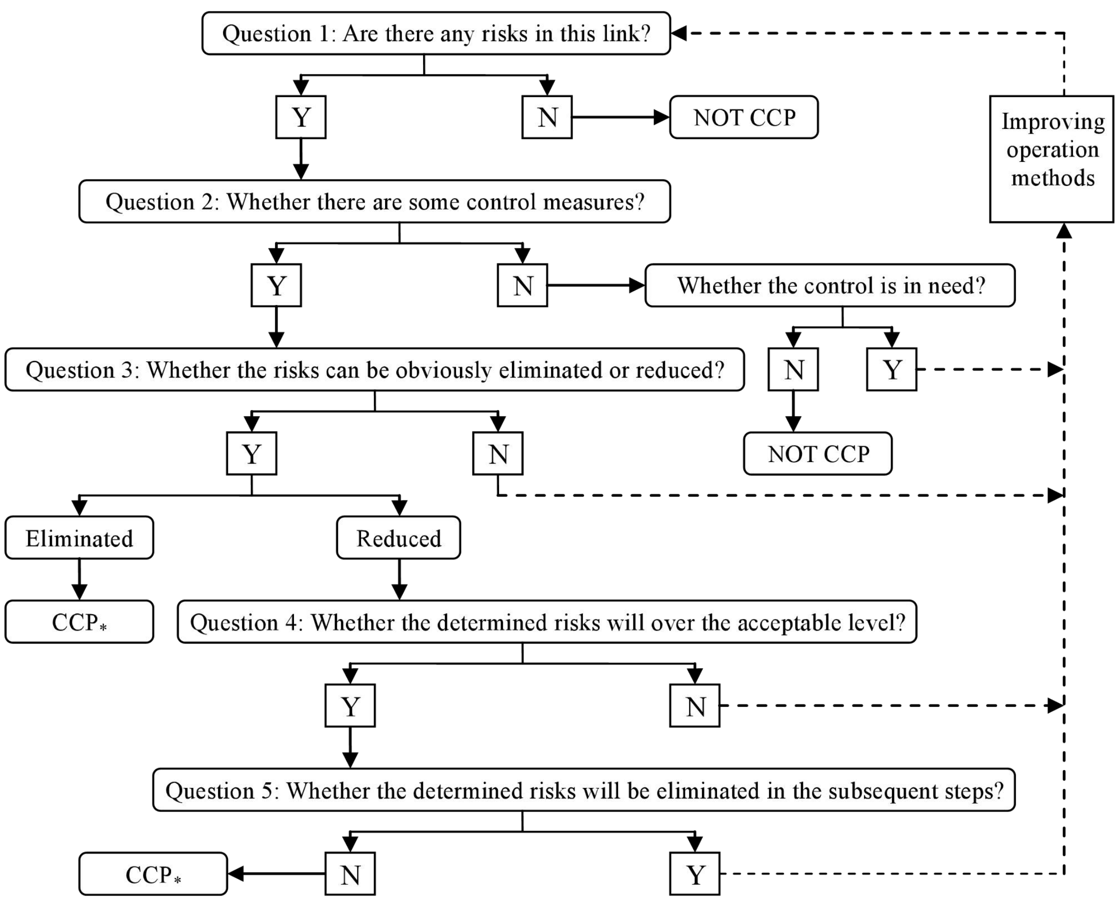

Fig. 6. Determination process for CCP*

Finally, after introduced the characteristics of GS1, we explored the building process of a quality and safety control system which is based on the combination of HACCP method and GS1. As is shown in Fig. 7, the quality and safety control system which was proposed in this paper is an effective way to guarantee the safety and quality of the dairy product. For one thing, it could supervise, analyze and control safety hazards for every links of the supply chain, and for another, it could regard supply chain as an information chain, in consequence, all the factors which could impact the safety of the food can be shared, tracked, located, and analyzed immediately. This system could not only ensure the safety and quality of the dairy products, but also constantly improve and optimize the system itself.

In future studies, the flow of HACCP would be more and more meticulous and standardized, meanwhile, with the rapid development of information technology, food quality and safety control system would be more widely and conveniently applied in the food industry. It could definitely improve the quality and safety of the food products, and rebuild the confidence of customers in China’s dairy market.

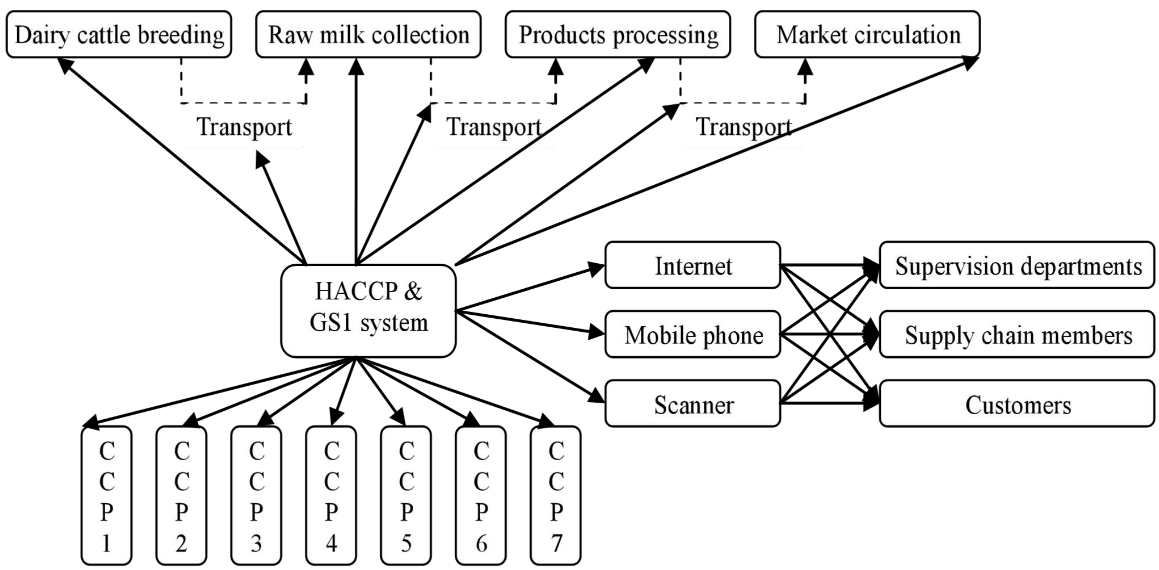

Fig. 7. Quality and safety control system of dairy supply based on the combination of HACCP & GS1

6.2 The second paper: An Agri-food Supply Chain Traceability System for China Based on RFID & Blockchain Technology

In the last paper, we established a quality and safety control system for China's dairy supply chain. However, this system is a typical centralized system, and an important question it has not considered is that whether the information shared by supply chain members in the traceability system can be trusted. Therefore, in this paper we proposed blockchain technology to solve this kind of issue, and based on blockchain technology and RFID to build a new decentralized traceability information system for the agri-food supply chain.

At first, after introduced the RFID and blockchain technology, the basic concept of agri-food supply chain traceability system based on RFID & blockchain technology has been given.

Secondly, a comparative analysis between centralized traceability system and our new decentralized traceability system has been demonstrated. As is shown in Fig. 8, supply chain members rely on an information supervision center to transfer and share their information, which fulfills the informatization and intelligentization of agri-food in the processes of production, processing, warehousing, distribution, sales and traceability management. This centralized traceability system effectively implements the information sharing and, to some extent, realizes the traceability management in the whole agri-food supply chain.

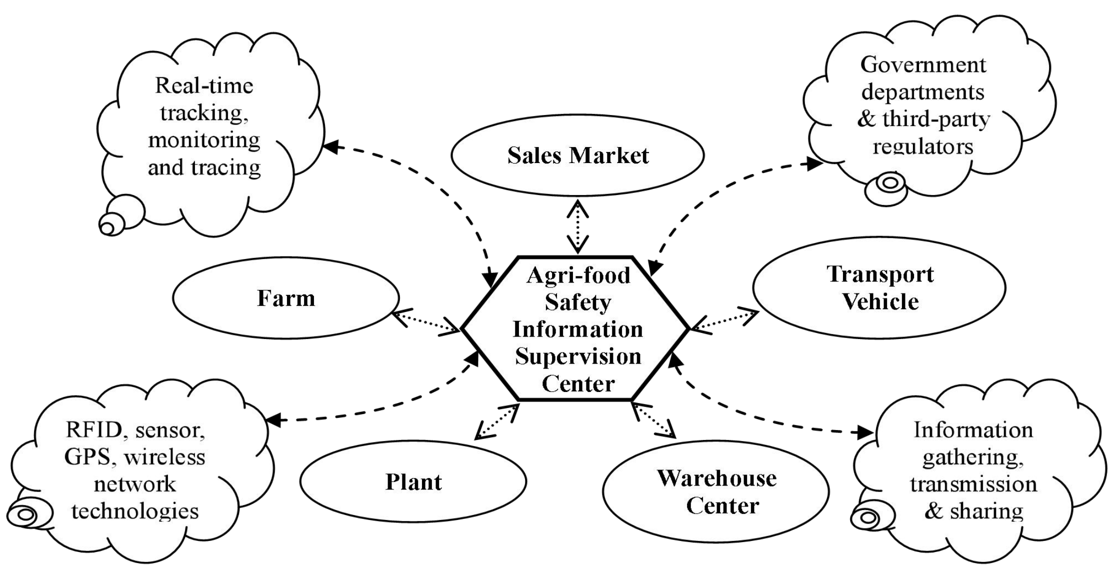

Fig. 8. Conceptual framework of centralized agri-food supply chain traceability system

However, as said above, this centralized is a monopolistic, asymmetric and opaque information system, which could result in the trust problem, such as fraud, corruption, tampering and falsifying information. As is shown in Fig. 9, our new traceability system which has applied blockchain technology could solve these issues of centralized organization (details will be discussed in paper 2). In this system, instead of being an information supervision center, government departments and third-party regulators are just some normal nodes of the system, just like all the other members of the system. However, they also have their own responsibilities, such as forcing the application of RFID in the entire agri-food supply chain, and inspecting the authenticity of the information uploaded by supply chain members. By using RFID & blockchain technology, this new decentralized traceability system could become a disruptive innovation which could increase the transparency of the supply chain, strengthen the information credibility, realize the real-time tracking of agri-food, and consequently, enhance the safety assurance of the agri-food supply chain.

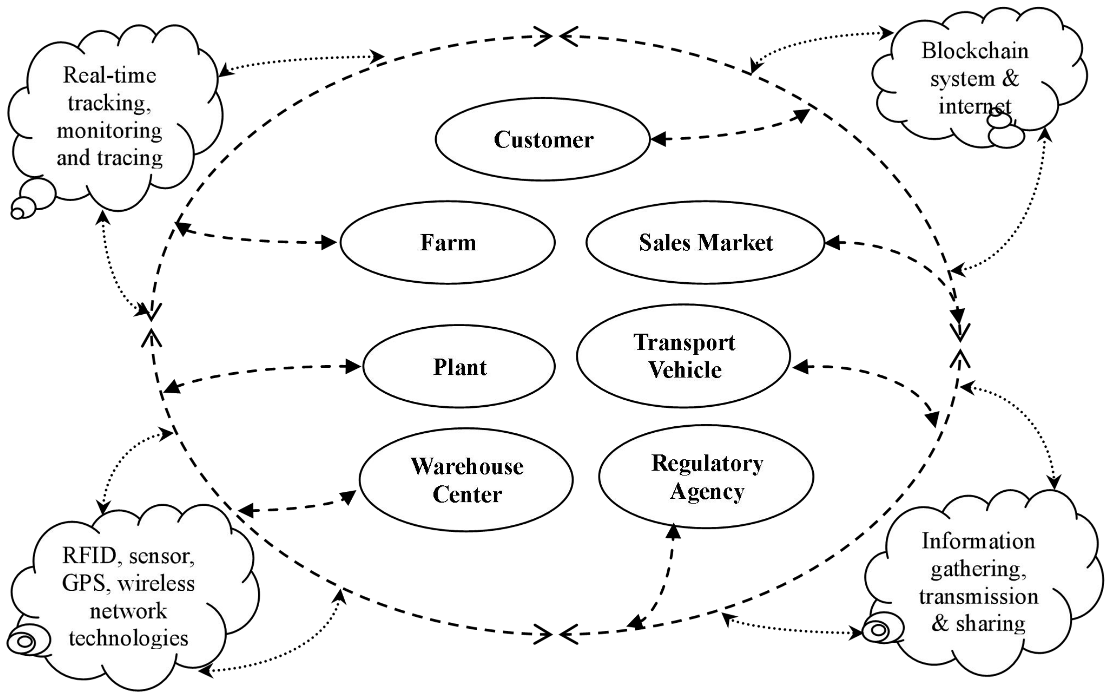

Fig. 9. Conceptual framework of an agri-food supply chain traceability system based on RFID & blockchain technology

Finally, after analyzed the advantages of our decentralized traceability system, the information journey of agri-food products through the whole supply chain within our new traceability system has been given to demonstrate the building process of this decentralized traceability system. This system covers the whole process of data gathering and information management of every links in agri-food supply chain, which realizes the monitoring, tracing and traceability management for the quality and safety of the agri-food "from farm to fork", and effectively guarantee the quality and safety of the agri-food products.

In future studies, with the rapid development of blockchain technology, building a decentralized traceability system in which the information can be completely trusted is the development tendency of the logistics industry. And if the application cost can be significantly reduced and its technical standard can be unified, RFID technology will be more widely used in the logistics industry, especially in agri-food logistics industry. There is no doubt that with the application of these emerging technologies, products can be understood, carried, checked and trusted as they travel along the supply chain. This will effectively enhance the quality and safety of agri-food products.

6.3 The third paper: A Supply Chain Traceability System for Food Safety Based on HACCP, Blockchain & Internet of Things

Based on the ideas of the last two papers, this paper combined HACCP, blockchain and internet of things to build a supply chain traceability system for food safety. This new system can significantly improve efficiency and transparency of the food supply chain, which will obviously enhance the food safety and rebuild the consumer's confidence in the food industry.

In the first place, take crop plant production as an example, the food supply chain has been associated with HACCP in different links are identified in Table. 4, and relevant processes and actions can be further supported by our new traceability system. Besides that, we also used BPMN to demonstrate how HACCP be connected within different processes along the food supply chain, and relevant solidity codes can be obtained also.

Table 4. Typical hazard controls for the food suppl chain

Control	Hazard	Control Measures	Monitoring	Corrective Actions
A1	Safety risk from background environment	Site assessment as part of assured scheme (e.g., quality of the soil, water, air, sunlight)	Regulator approval; routine reassessment	Review site classification; Reassess site designation; document action taken
A2	Safety risk from seed	Seed produced according to accepted practices; seed purchased from reputable suppliers; seed passing the quality test	Regulator approval; site documentation; supplier documentation	Document actions taken; review supplier status
A3	Safety risk from field practices (growing)	All field practices according to good working practices and recording growing information (e.g., variety, item No, producing area, growth conditions, staff)	Site documentation	Review procedures; review workforce training; document actions taken
A4	Excess residues of applied fertilizers and pesticides	All applied fertilizers and pesticides purchased from reputable suppliers; recording the applied situation.	Regulator approval; supplier documentation; site documentation	Review supplier status; review producer; review workforce training; document actions taken
A5	Safety risk from field practices (Harvesting)	All field practices according to good working practices and recording harvesting information (e.g., planting time, plucking time, staff)	Site documentation	Review procedures; review workforce training; document actions taken
B1	Safety risk associated with processing environment	Site assessment as part of assured scheme (e.g., temperature controlling, disinfecting, processing equipment)	Regulator approval; routine reassessment; site documentation	Review site classification; Reassess site designation; document action taken
B2	Safety risk associated with processing step	All processing practices according to good working practices, and process additives used for suitable for their intended purpose	Site documentation; supplier documentation	Review procedures; review workforce training; document actions taken; review supplier status; document actions taken
B3	Safety risk associated with	All packaging materials and practices according to good working practices	Site documentation;	Review procedures; review workforce training;

	packaging		supplier documentation	document actions taken; review supplier status; document actions taken
C1	Safety risk from site equipment	Ensure all equipment properly maintained (cold storage, temperature and humidity controlling systems)	Maintenance records	Review maintenance procedures; review workforce training; document actions taken
C2	Safety risk from warehouse management	All warehouse management practices according to good working practices (e.g., recording environment of the cold storage, quality and storage time of products)	Site documentation	Review procedures; review workforce training; document actions taken
D	Safety risk from site equipment	Ensure all equipment properly maintained (e.g., refrigerated truck)	Maintenance records	Review maintenance procedures; review workforce training; document actions taken
E	Safety risk associated with retail management	All retail management practices according to good working practices (e.g., using the refrigeration; checking the lifetime; replacing expired products)	Site documentation	Review procedures; review workforce training; document actions taken

Secondly, we briefly introduced the characteristics and working principles of the blockchain and smart contract. Besides, in order to deal with the scalability issues of blockchain, we proposed the concept of BigchainDB in our system. Then, we demonstrated the structure of our traceability system. Since there are many participants in our system, including suppliers, producers, manufacturers, distributors, retailers, consumers and certifiers, we explained the role of these participants running in our system and how it can provide an information platform with openness, transparency, neutrality, reliability and security for them.

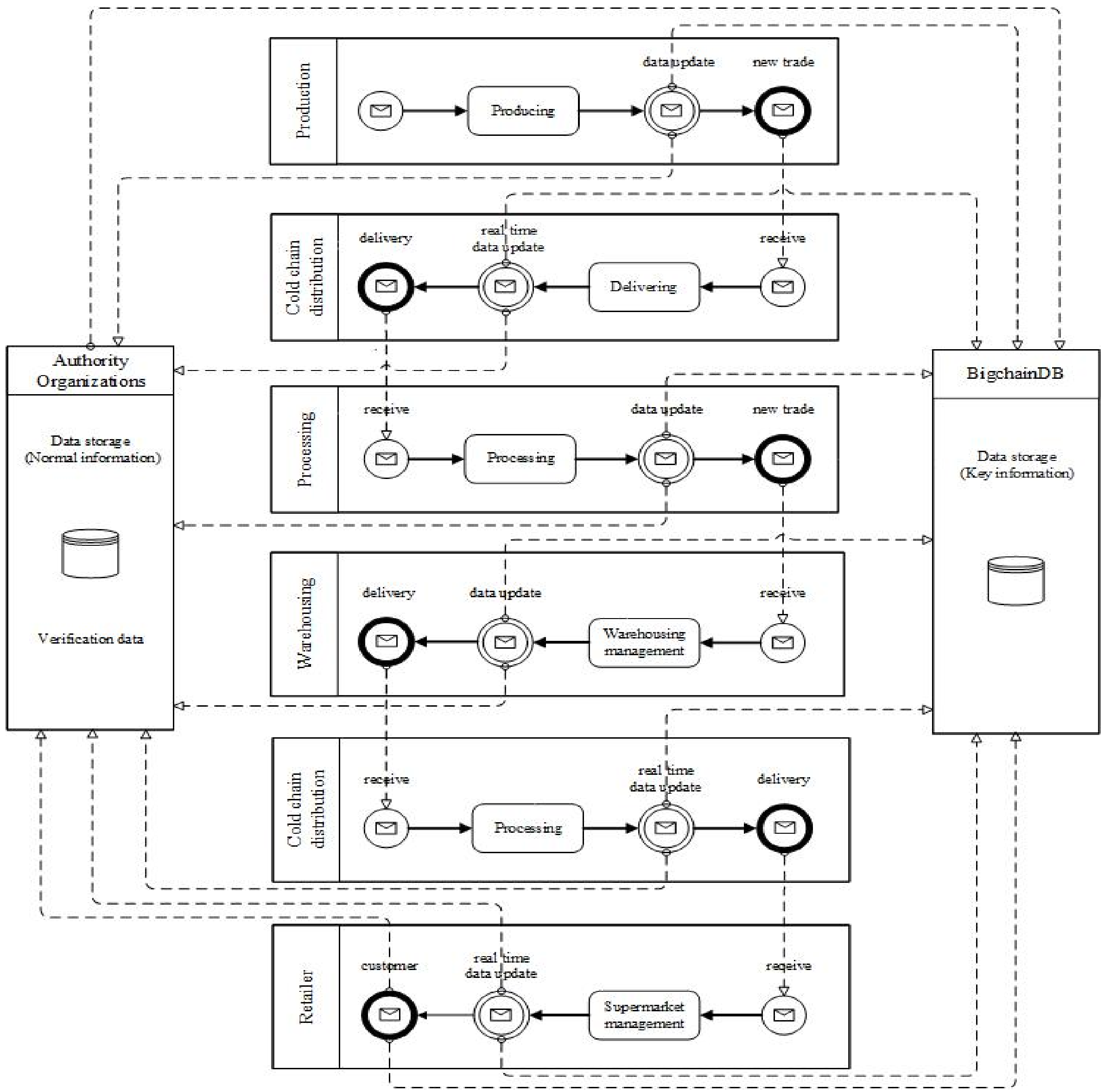

Fig. 10. Information flow diagram for the food supply chain participants within our traceability system

Finally, an example application scenario is given to show how actions in HACCP can be supported by our proposed traceability system.

This system will deliver real-time information to all supply chain members on the safety status of food products, extremely reduce the risk of centralized information systems, and bring more secure, distributed, transparent, and collaborative. Our system can significantly improve efficiency and transparency of the food supply chain, which will obviously enhance the food safety and rebuild the consumer's confidence in the food industry.

However, this system is still in an initial stage. First of all, this system requires advanced IT infrastructure for all members in the supply chain, which maybe too difficult for some participants at the moment. Secondly, this system should prove that it can bring real business benefits, otherwise, supply chain members won't share the cost for application. Finally, there is a possibility: if there is a super monopoly enterprise which is so powerful that can control the whole supply chain and even the chain-of-custody system, it can enter wrong information and hide the criminal fact, which means the data can be tampered with the sensors. I have to admit that this is the weak link of our system, and we believe that it will be an interesting topic for future researches.

6.4 The fourth paper: Evaluation Research on Performance of Chinese Agri-Food Cold-Chain Logistics Company

In the last paper, we proposed a decentralized traceability system for improving the food safety in the food supply chain areas. However, how can the improvement in food safety and performance of supply chain management through such a system be measured and evaluated is the question for this research. Since it is the first such artifact that is designed for food supply chain management for food safety, it is impossible to make a case study. Therefore, this paper constructed a performance evaluation model by improved AHP and fuzzy comprehensive evaluation methods for the agri-food cold-chain logistics company, which plays a very important role for food safety also. We believe that, with this method, if our artifact can be widely used in the business environment in the future, empirical studies and tests can be implemented more in depth.

At first, based on the literature review and the questionnaire survey, an agri-food cold-chain logistics enterprise performance evaluation index system was constructed based on the BSC.

Secondly, by using improved AHP method, the final indexes weights can be obtained. Then, based on these final indexes weights, we can calculate the final evaluation score of the target index in each level by using the fuzzy comprehensive evaluation method.

Finally, an illustrative was given to show the process of how to obtain the final evaluation scores for the target company. Then, based on the final scores, relevant management suggestion can be given for result analysis.

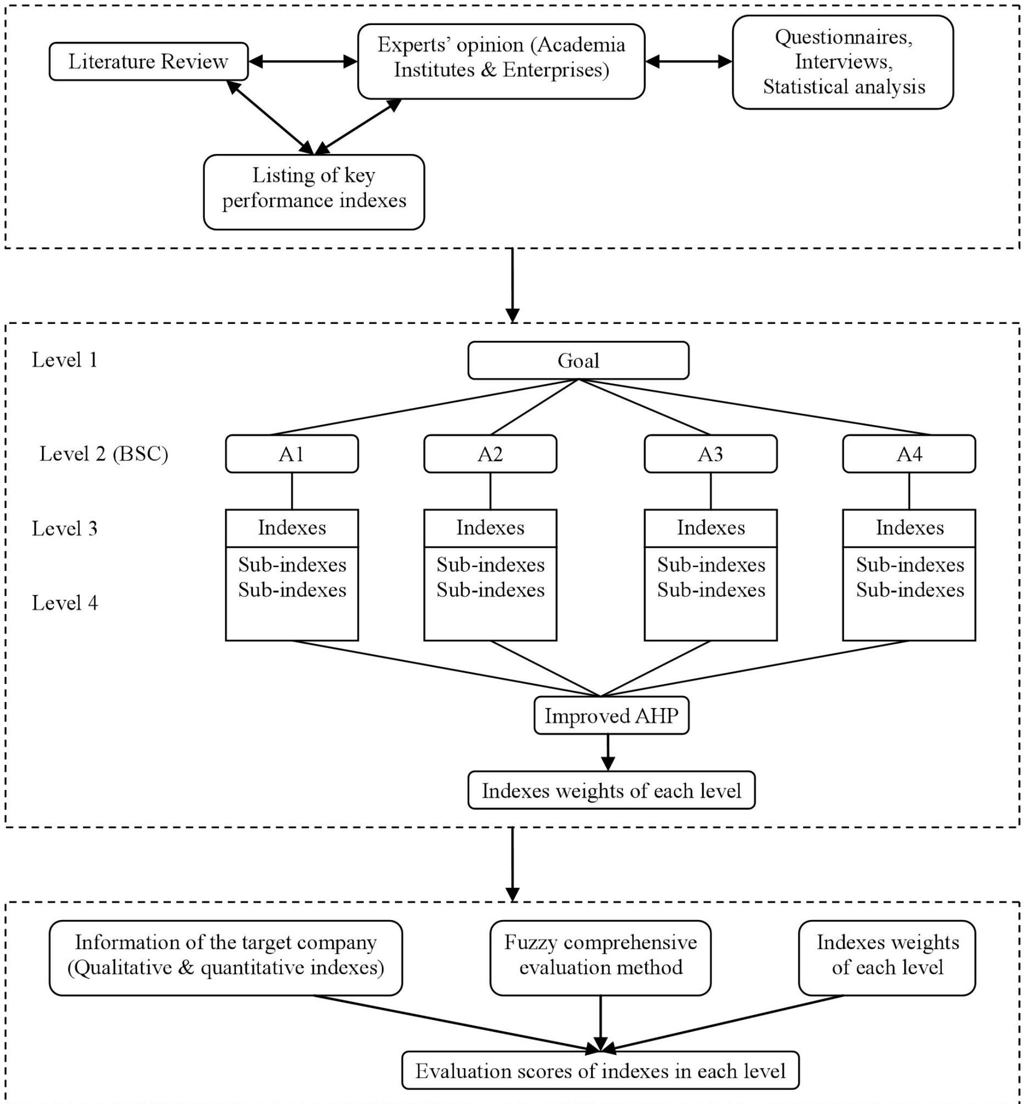

Fig. 11. Generalized framework for performance evaluation through Fuzzy-AHP method

This paper constructed a performance evaluation model by improved AHP and fuzzy comprehensive evaluation methods for the agri-food cold-chain logistics company. It provides a practical solution by which agri-food cold-chain companies could easily understand the present strengths and weaknesses of themselves. Therefore, necessary actions can be taken into account to address them. Furthermore, this model can be also used for evaluating and selecting the cold-chain 3PL enterprises by the agri-food suppliers. However, there are some limitations in this study. One of the limitations is that the hierarchical structure model was built based on the literature review. Nevertheless, within the cold-chain industry, different companies face the different market environment and have their own operation status. Therefore, a hierarchical structure model should be specifically developed to reflect the nature of the business. Another limitation is that fuzzy AHP include experts' questionnaire survey which can be viewed as the subjectivity rating process. And different people will hold different opinions concerning the rating of one attribute over another.

The suggestion for future research is increasing the sample size of the questionnaire survey which could provide more data for the study to obtain a better research result. Besides, different evaluation indexes can be chosen for the different companies, as per their own market environment, goals and business strategies.

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Paper 1: A Quality and Safety Control System for China's Dairy Supply Chain Based on HACCP & GS1

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A Quality and Safety Control System for China's Dairy Supply Chain Based on HACCP & GS1

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ABSTRACT

In recent years, food safety accidents have frequently happened in China's dairy industry, which makes people have already lost their confidence in China's dairy market. Therefore, building a set of quality and safety control system to ensure the quality and safety of dairy products has become more and more urgent. As a systematic preventive method for food safety, HACCP (Hazard Analysis and Critical Control Points) has been widely used in each link of the food supply chain. It could analyze and control safety hazards at every key point of the food supply chain. However, the information of these points in the different parts of the supply chain is isolated. In this paper, we propose a quality and safety control system of the dairy supply chain based on the combination of HACCP and GS1 (Global Standard 1). By using GS1, this system could connect all the HACCP points along the dairy supply chain, and implement information collecting, transferring, storing, checking, and sharing among the supply chain members, which could effectively improve the supply chain efficiency, and guarantee the quality and safety of dairy products.

Keywords - Dairy supply chain; quality and safety control system; HACCP; GS1; food safety

1. INTRODUCTION

Nowadays, with the rapid growth of China's economy and the constant improvement of living standards, people's demand for dairy products is increasing day by day. It is estimated that in 2013 the total output of liquid milk in China was around 23.02 million tons, and the total value of dairy products cold-chain industry was up to 71.89 billion RMB [1]. However, compared with developed countries in Europe and North America, China's dairy industry is still at the primary stage of development, and there are many serious problems in quality and safety management. For example, in recent years, there has been an increasing number of food safety scandals, such as "Sanlu toxic milk powder", "caustic soda scandal of Bright Dairy & Food Company" and "tainted infant formula", which have contributed to a loss of consumer confidence in China's dairy markets, and made the development of China's dairy industry suffered a deathblow.

Even more important, these scandals indicate that discovering and controlling these kinds of safety events has serious hysteresis quality. Therefore, building a quality and safety control system for dairy supply chain which could implement monitoring, analysis, controlling, and tracing management for the entire diary products supply chain has become an urgent requirement. Once a safety accident happens, the source of the accident could be found and the defective products could be recalled immediately, which could maximally protect consumers' benefit, rebuild enterprises' reputation, and restore consumers confidence in China's dairy industry.

Based on the analysis above, the primary objective of this paper is to build a quality and safety control system based on the combination of HACCP and GS1 (a kind of global standards system for product identification) for helping China's dairy industries to enhance their products' quality and safety. The remainder of the paper is organized as follows. We begin with a brief overview of existing literature on the researches of quality and safety management of the dairy supply chain in section 2. Then we study the structure of dairy supply chain in section 3. In section 4, we analyze the basic structure of China's dairy supply chain, including dairy cattle breeding, raw milk collection, dairy products processing, and market circulation, through an HACCP method. At the same time, in section 5 we demonstrate the application of the GS1 which could realize information sharing and tracing for the whole dairy supply chain. After that, we propose a quality and safety control system of the dairy supply chain based on the combination of HACCP and GS1 in section 6. Finally, we make a brief conclusion for this paper in section 7.

2. LITERATURE REVIEW

Food quality and safety are always the key factor for food supply chain management. How to guarantee the quality and safety of the food has been widely studied in relevant areas. Valeeva et al. (2005) [2] divided dairy supply chain into 4 blocks: feed, farm, dairy processing, and consumer. And focused on the analysis of two main groups of hazards: chemical and microbiological by using conjoint analysis. Their study shows that controlling the chemical hazards are more vital for feed and farm blocks; while controlling the microbiological hazards are considered more vital for farm and dairy processing blocks. In order to improve Chinese food safety record after China melamine milk scandal, Pei et al. (2011) [3] made a comparative benchmark study design comparing the Chinese dairy sector with Austrian dairy sector in aspects of regulatory issues, official controls, and private standards. Kumar et al. (2011) [4] presented a case study to identify the determinants of compliance with food safety measures in dairy supply chain in India. Their study indicates that the adoption intensity of products safety practices could be influenced by the characteristics of the dairy farmers, such as herd size, education level, and specialized knowledge in dairying. Moreover, the highly integrated dairy farmers with modern dairy supply chain have positive impact on the adoption intensity of products safety practices at the farm level. Chen et al. (2014) [5] developed an analytical model and case studies to investigate the milk scandal in China. With this model, quality control is quantitatively analyzed in centralized and decentralized supply chain. And the impacts of the pricing and regulatory policies on the quality and profit of the product are deeply explored in their case studies.

Several researchers specifically considered the using of HACCP in food safety and supply chain management. Henson & Holt (2000) [6] explored four key factors, namely, internal efficiency, commercial pressure, external requirements, and good practice, which could motivate the using of food safety controls by businesses through a study of HACCP adoption in the U.K. dairy processing sector. Their research results show that there are systematic differences in the HACCP adoption process between companies. Sperber (2005) [7] pointed out the lack of definitive critical control points which could hamper the effective application of HACCP in the entire supply chain. And we must focus on the application of effective food safety control measures rather than the critical control points from a HACCP system. Papademas & Bintsis (2010) [8] conducted a comprehensive literature review on food safety management systems in the dairy industry. They focus on the HACCP and relevant EC (European Community) regulation which are implemented by the dairy industry. Since food cold-chain is very vulnerable to suffer from safety hazards, a risk assessment principle is badly needed to ensure the safety of the cold-chain. By using HACCP, Zhang & Chen (2011) [9] analyze all steps of the cold-chain, assess the potential risks, identify the CCPs, and give the relevant risk weights, so as to implement a entire risk assessment system for guaranteeing the safety of the cold-chain.

With the rapid development of information technologies, several other researchers tried to apply these technologies in food supply chain management area in many different ways. Based on the concept that data must be gathered, stored and shared in each link of the supply chain, Manikas & Manos (2009) [10] developed a model which realizes the traceability in the food supply chain. This model consists of three steps, natural environment, transformation, and distribution, which represent the stages of the real-life supply chains. They insisted that this model could be the basis for the development of a web application for traceability management in the dairy supply chain. Grunow & Piramuthu (2013) [11] developed a model and studied the application of RFID technology in a high perishable food supply chain from the perspectives of the distributor, retailer, and customer. In their model they found that the investment in the application of RFID technology could benefit the distributor, retailer, and customer when facing the issue of remaining shelf-life in the food supply chain. Cao et al. (2014) [12] built general framework for animal food safety traceability by using RFID tags encoding with EPCglobal tag data standards. In this framework, discovery service and object name service are used to locate dynamic distributed information servers for dynamic data sharing.

As discussed above, several studies have considered the use of HACCP and information technologies in food supply chain management. However, most of these studies only focused on the relevant standards, process, regulatory issues, government policies, and cost and benefits associated with the implementation and operation of HACCP in food supply chain; or concentrated on the technical functions of various information technologies which could be applied in the food supply chain. It is worth noting that there is an important issue they have not touched. HACCP can be used to analyze and control the hazards at each key point of the entire dairy supply chain, including the links of dairy cattle breeding, raw milk collecting, dairy product processing, and market circulation. However, the information of each point of HACCP along the supply chain is isolated. Therefore, this information must be connected along the whole dairy supply chain, and only in this way the quality and safety of the dairy products can be effectively guaranteed. In this paper, based on the analysis of structure and potential hazards of China's dairy supply chain, we integrate GS1 into HACCP to build a quality and safety control system. It could connect every isolated HACCP point along the dairy supply chain, and realize the information collecting, storing, transferring, checking, and sharing among the supply chain members. This system could effectively strengthen the quality and safety of dairy products, especially in today's China's dairy market.

3. STRUCTURE OF THE DAIRY SUPPLY CHAIN

The dairy supply chain is composed by the links of dairy cattle breeding, raw milk collection, dairy product processing, and market circulation. It is a complete supply chain: "from farm to fork".

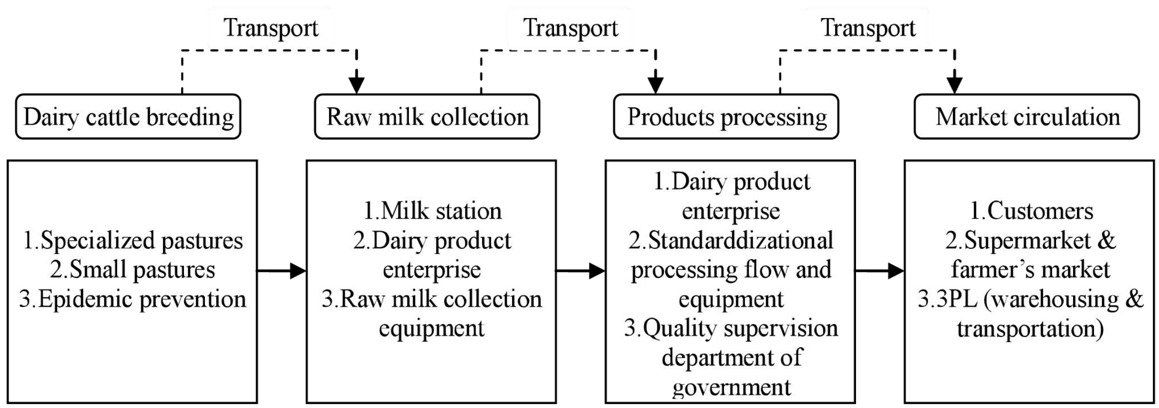

Fig. 1. Basic structure of dairy supply chain

3.1 Dairy cattle breeding

Main task of this stage is guaranteeing the quality and quantity of raw milk production. Therefore, details of the dairy cattle breeding should be implemented according to the standards, such as the type of fodder, application of RFID, epidemic prevention, process of raw milk production, etc.

3.2 Collection of raw milk

In China, producing areas of raw milk mainly include specialized pastures which belong to the huge monopoly dairy products enterprises such as China Mengniu dairy company limited and Inner Mongolia Yili industrial group limited, and small pastures which belong to the individual dairy farmers. Preservation treatments need to be taken immediately once raw milk is collected, and then it should be sent to the dairy processing enterprise immediately. Since the quality of raw milk is the key factor for guaranteeing the safety of the dairy products, for specialized pastures, raw milk is collected by professional equipment, meanwhile, for small pastures, individual dairy farmers need to send their dairy cattle to milk station for unified collection.

After collection, the temperature of the collected raw milk needs to be dropped below 4°C by using panel cooler for storage. And then, during the whole transportation process, the temperature should be controlled at 2°C-4°C [13]. Milk tankers are widely used during this cold-chain transportation process. Therefore, the operation and management of the milk tanker are very important and necessary. First of all, milk tanker needs to be thoroughly rinsed and disinfected before use. Secondly, milk tanker should be maintained in fill-up status to avoid oxidative deteriorated which is caused by the contact between raw milk and the residual air in the tank. Moreover, the residual air could impact the temperature control of the raw milk.

Before being sent to the dairy processing enterprises, raw milk should be rigorously detected. After that, raw milk which has passed the detections will be sent to the production line automatically through the vehicle equipment of milk tanker, and then finish the unloading process. However, raw milk will be returned if it can not pass the detections, and prevent this kind of unqualified raw milk back into the processing enterprises is even more important.

3.3 Dairy product processing

In order to guarantee the safety and quality of dairy products, some standards should be adopted for raw milk's purchasing and processing, meanwhile, all the processing stages should be closely monitored. With regard to the problem of additive abuse, firstly, the using of additive should be strictly controlled and be according to the rules to avoid possible hazards. Secondly, the classified management and storage for food addictive are also very important. Therefore, relevant staff should fully understand the storage condition, the chemical principle, and the hazard of the addictive, so as to take reasonable methods for storage and transportation.

Dairy products are automatically processed on the assembly line in all processing stages. More importantly, due to the characteristic of the dairy, the temperature and humidity should be controlled in a standard range during the whole processing link.

3.4 Market circulation link of the dairy product

This link mainly contains warehousing and transportation, and market sales of the dairy product. In the warehousing and transportation stage, the 3PL (Third-Party Logistics) companies which could provide professional logistics service and guarantee the safety and quality of the dairy product in this process are widely used. Through distributors of all levels, dairy products finally flow into the market places, such as supermarket and farmer's market.

According to the characteristics of different dairy products, the entire process of warehousing and transportation should meet the requirement of the standard. Take liquid milk as an example, it should be sent to cold storage for refrigeration immediately, once the disinfection and processing processes have been finished. The temperature of the cold storage should be maintained at 2°C-4°C, and the refrigeration capacity of the cold storage should satisfy the needs of at least 95% of the inventory [13]. Besides that, the staff of the cold storage should timely record the running state of the cold storage, and carry out loading immediately when they receive the distribution information. During the distribution stage, the temperature and humidity should be maintained in the standard range in the entire process, and real time information recording and transferring of the temperature and humidity should be implemented as well. Generally speaking, when the liquid milk product has been produced, it should be put onto the shelf as quickly as possible. And this period should be no more than three days. Otherwise, the product will be rejected by the retailer because of the safety and quality reasons.

4. QUALITY AND SAFETY CONTROL PROCESS OF DAIRY SUPPLY CHAIN BASED ON HACCP

4.1 The building of the HACCP system

HACCP can be used to comprehensively analyze various potential hazard factors which could cause food contamination for the entire dairy supply chain. Thanks to this approach, critical control points which contain hazardous factors can be effectively controlled, and thus achieve the aim of eliminating or reducing the food safety hazard to an acceptable level. As a systematic preventive approach for food safety, HACCP has been widely used around the world, and in some countries and international organizations it even has been forced to apply in food industries.

Building a complete HACCP system mainly includes the following steps:

(1) **Establishment of HACCP team**. The establishment of HACCP team is a top-down process, which needs the full involvement and support of the top managers of the

company. The HACCP team consists of operation and management staff who have professional knowledge about products, sometimes even including some experts from different areas.

(2) **Product description**. HACCP team members should fully describe the product of the company, like the dairy product in this paper, such as product introduction (product name, main components, and source of raw materials), physical and chemical properties, processing method, type of packaging, expiration date, the way of storage and sales, etc.

(3) **Determining the consumer groups**. Determining the consumer groups will directly impact the result of the hazard analysis in the future.

(4) **Drawing process flowchart**. Production procedures should be numbered sequentially with some instructions, and relevant potential hazards should be also indicated in the flowchart, so as to implement hazards analysis in the future. The HACCP team should revise the process flowchart through on-site inspection and practical operation when the process flowchart has been finished.

In the following sections, we will demonstrate how to use the HACCP method to analyze the factors which affect the safety and quality in each of the links of the dairy supply chain.

4.2 Hazard analysis

4.2.1 Dairy cattle breeding link

In this link, the factors which could affect the safety and quality of raw milk are the potential hazard factors, such as the quality of the grass, pasture environment, health condition of the dairy cattle, etc. China’s dairy industry has developed very rapidly in recent decades, but there are still many problems and defects which could cause potential hazards to the safety and quality of the dairy product.

In the first place, currently the individual dairy farmers still occupy the major proportion of China’s dairy cattle breeding industry. These individual dairy farmers have their inherent defects, such as small scale, lack of money, lag in technology, and poor breeding conditions. According to a statistics which shows that the average number of dairy cattle ownership among the individual dairy farmers is 3-5, and those who have more than 20 dairy cattle only account for less than 25% [14]. Even worse, most of these farmers almost do not have any professional knowledge and skill for dairy cattle breeding, and in fact they are more ordinary peasants than dairy cattle farmers. On the other hand, since dairy cattle breeding is a high-cost and low-profit link in the whole dairy supply chain in China, in order to chase higher profit many farmers choose to produce adulterated milk, which could bring huge potential safety hazard to the dairy product. Secondly, due to the lack of high quality natural grass and fodder, sometimes dairy cattle was fed by low-quality straw, ordinary grass, and fodder, which seriously influences the quality and yield of raw milk. Finally, because of the shortage of supporting facilities, safety issues are still very serious during the milking process. For example, hand milking method is still widely used among the individual dairy farmers, which has many fatal flaws including long time operation, unable to refrigerate raw milk immediately, unqualified disinfection [15], and could result in the contamination of raw milk.

4.2.2 Collection of raw milk

As an intermediate link between dairy farmers and dairy processing enterprises, milk stations, to some extent, offset the shortcomings of China's dairy cattle breeding which is still in the stage of low degree of organization. However, as an independent profit organization, milk stations desire to pursuit profit maximization. Therefore, milk stations will have the motivation to make adulterated milk as well, when their profits are dwindling. In addition, until now in China there is no specific department which is responsible for the supervision of the milk station, and relevant national testing standards are also imperfect [16]. These would bring harm to the safety of dairy products obviously.

After the scandal of the "Sanlu milk powder", functional departments of the Chinese government have enhanced the strength of supervision and administration in the production of dairy products. And most of the milk stations have established a series of the quality and safety detection systems. However, these systems have not been implemented strictly. For instant, some milk stations seemingly have complete documents (vaccination certificate, trading certificate, health certificate), but their hygienic conditions are still very bad and their operational processes are also irregular.

4.2.3 Dairy products processing

As the core of the dairy supply chain, the potential safety hazards of dairy processing enterprises include: first of all, the source of milk mainly relies on milk stations and individual dairy farmers. Since they do not have a reliable quality and safety control system, once safety accident happens, dairy products enterprise can not eliminate and control the hazard immediately, further more, relevant accountabilities can not be investigated smoothly.

Secondly, although China's dairy industry markets developed really rapidly, the market supervision still seriously lags behind. All the dairy products enterprises pursue the grandiose development patterns, and therefore fierce price wars constantly squeeze the production cost and profit margin, which make the whole dairy industry market grievously deviate from its healthy development track.

Last but not least, there are some other human and non-human factors which could influence the safety of dairy products during their processing stage. Human factors including: in order to reduce the production cost, massive malted milk and sucrose are used instead of raw milk; for the purpose of improving some quality index of the dairy products, some harmful chemical additives are mixed in raw milk. And non-human factors: as some dirty equipment, such as filter, cooler, milk tanker, etc, are used or touched with dairy products during their processing, transportation and storage stages.

4.2.4 Market circulation link

In market circulation link, the potential hazard factors for the dairy products mainly come from the external environment. Therefore, cold-chain ability is the key to ensure the safety and quality of the products. The dairy products, including fresh milk, yogurt, ice cream, are a kind of highly perishable products with extremely short guarantee period, so cold-chain equipment need to be widely applied in their logistics and sales process to prevent products from spoiling. Besides that, sales status of the dairy products, such as sales quantity, date, environmental data of transporting and storage, should be completely recorded.

4.3 Determination of the CCP (Critical Control Points)

Based on the hazard analysis above, the CCP can be determined. There are three principles in the determination of the CCP: the hazards can be forecasted, reduced, and eliminated at these critical points. As is shown in Fig. 2 the critical points can be determined by using the CCP decision tree. In this paper, we take the CCP of the China Mengniu dairy company limited [17] as an example, the CCP of the dairy products in different process of supply chain are: in dairy cattle breeding link are the quality of the grass (CCP1) and the healthy condition of the dairy cattle (CCP2); in raw milk collection link are the quality of raw milk (CCP3) and the warehousing and transportation equipment (CCP4); in dairy products processing link are the standardization of the processing flow (CCP5) and the quality of the staff (CCP6); in the market circulation link is the cold-chain ability during the distribution and sales process (CCP7).

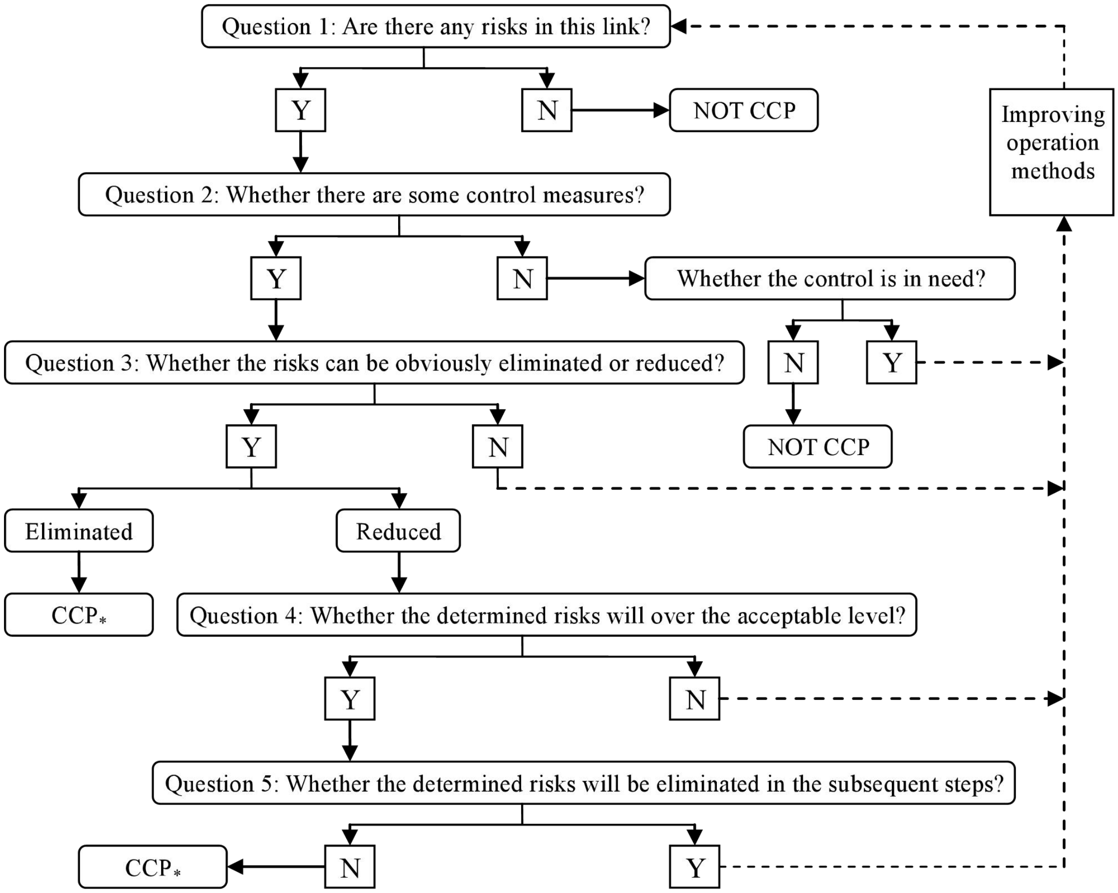

Fig. 2. Determination process for CCP*

4.4 Establishment of critical limits

Critical limit is a kind of controlling index for ensuring the safety and quality of the food. In many cases, critical value can not be obtained directly, and we need to refer the relevant academic publications, industry standards, regulatory requirements, and expert opinions, etc. As the most famous China's dairy company, the products of Mengniu dairy company limited are well sold all over the country and it has enormous influence in China's dairy industry. Therefore, the relevant standards which are used in its critical limits establishment are very strict and internationalized.

The quality standard of the grass refer to the law of 20-30-40, which means the crude protein level of the grass should be above 20%, content of the ADF (Acid detergent Fiber) should be below 30%, and the content of the NDF (Neutral Detergent Fiber) should be no more than 40% [17].

Dairy product's logistics transportation, quality inspection, and relevant cold-chain ability mainly rely on the advanced degree of the equipment. Therefore, in order to up to the international safety standards, like the Mengniu company, every year huge funds have been invested to equipment purchasing and maintenance.

The standardization level of the manufacturing procedure depends on the personnel quality, including educational background, operation capacity, and even moral level. For example, with the high standardization level of the manufacturing procedure, some man-caused accidents like intentionally adding water or various kinds of chemical additives into dairy products could be avoided to a large extent.

5. APPLICATION OF GS1 IN QUALITY AND SAFETY CONTROL SYSTEM OF DAIRY SUPPLY CHAIN

5.1 Introduction of GS1

GS1 is a kind of globalization standard system, which takes the coding technology as the core and includes the functions of data collection, data exchange, identification of EPC (Electronic Product Code), global product classification, and global data synchronization. It covers the product, transportation unit, property, location, and service of global cross-industry, and makes the products can be scanned and identified all over the world. GS1 has three key characters: globalization, systematicness, and maintainability.

(1) **Globalization**. As an international standard, GS1 has been widely applied in global circulation area. Meanwhile, its encoding structure and distribution type could ensure the uniqueness of the coding.

(2) **Systematicness**. An entire GS1 system is established from three aspects: identification, carrier, and exchange. Firstly, GS1 builds a set of standard global coding system, which establishes the foundation for the application of efficient, reliable, and cheap automatic identification and data collection technology by encoding for the objects in the supply chain, such as goods, container, pallet, location, etc. Secondly, GS1 system takes bar code and RFID (Radio Frequency Identification) as the carrier and widely uses automatic data collection technology, which provides essential technical support for realizing the synchronous of material flow and information flow. Last but not least, GS1 system provides clear definitions and explanation for articles by using EANCOM (European Article Number Communication) for data exchange, which could help business partners mutual exchange

their business information with a simple, accurate, and cost-effective way, and as a consequence, it has been widely applied in global retail, financial, and transportation industries.

(3) **Maintainability**. The GSMP (Global Standard Management Process) is part of the GS1 system of standards used in world trade. It is an integral part of the GS1 standards development and maintenance process [18]. GSMP is an open, transparent and customer driven process, which allows for user member's active involvement from around the world. And it could ensure the maintainability of the GS1 system.

Thanks to GS1 system, information can be transferred and shared among the supply chain members, and more importantly, it could implement monitoring for the whole process of the dairy supply chain. Its main tasks are: data statistics, rejecting useless information, information checking, editing and feedback of valuable information, and sending classified information to the groups based on different demands.

5.2 The establishment of coding system

The precondition for GS1 system running in the dairy supply chain is a unified coding system and international standards should be widely used among all the dairy supply chain members. Only in this way, data identification, sharing, and exchange could be realized along the dairy supply chain.

As the main data carriers used in the dairy supply chain, the advantages and disadvantages of the code bar and RFID have been showed in Table. 1. According to their characteristics, code bar is always used on the huge number of single dairy products, which contains some basic information about the product, such as quarantine result, nutritional ingredients, and guarantee period. While, RFID is mainly used on the integrating packaged products, like pallet, packing-case, and container, etc, and high-value single product, like RFID ear tag for the dairy cattle. RFID could record much more information than the code bar, such as resource of raw milk, production time, storage time and method, transportation method, temperature, and humidity, etc. In addition, RFID ear tag could recode the information of the whole life of the dairy cattle, including the health condition, quality of the grass, quality and quantity of milk production, etc.

Table 1. Compare between Bar code & RFID

Compared items	Bar code	RFID
Reading mode	Electric scanning	Wireless
Information Capability	Small	Big
Security	Low	High
Environmental limit	Huge	Small
Scan speed	Slow	Fast
Scan distance	Very short	Far
Price	Low	High
Service life	Short	Long

5.3 The using of EDI (Electronic Data Interchange)

By using EDI, all useful information along the supply chain can be translated into standard electronic code according to a fixed protocol, which could make data to be saved, transferred, shared, and processed automatically among the supply chain members. In dairy supply chain, XML (Extensible Markup Language)/EDI which could write structured data based on its own system characteristics without being affected by suppliers and other factors has been widely used. Therefore, thanks to EDI the dairy supply chain can be seen as an information chain, and the final useful information can be shared with every supply chain members, supervisory authorities, and customers, through information collecting, processing, filtering, checking, and classifying.

6. QUALITY AND SAFETY CONTROL SYSTEM OF DAIRY SUPPLY CHAIN BASED ON THE COMBINATION OF HACCP & GS1

This quality and safety control system contains two parts which supplement each other. One is the safety and quality control mechanism based on HACCP, and the other one is the information sharing and tracing system based on GS1. HACCP method could control and supervise the safety of the whole dairy supply chain process; GS1 system could translate material flow into information flow, so as to promote information sharing and tracing along the whole dairy supply chain and connect every isolated HACCP point as well. Once a food safety accident happens, the relevant information can be traced and located, and emergency measures can be taken immediately to prevent the spreading of the Hazard.

Further more, relying on this information we could effectively fight against the fake commodities, safeguard the rights and interests of the customers, and guarantee the quality and safety of dairy products. Therefore, the combination of the HACCP method and GS1 system could not only ensure the safety and quality of the dairy products, but also realize information transparency sharing and tracing among the enterprises in the dairy supply chain. Fig. 3 shows the flow chart of the quality and safety control system of the dairy supply chain based on the combination of HACCP and GS1.

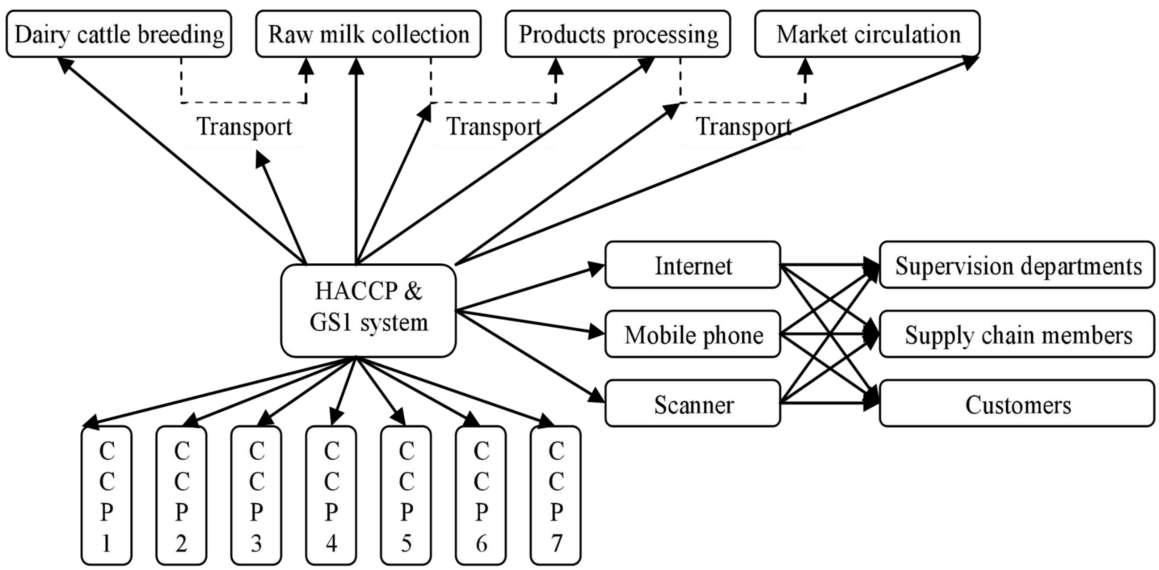

Fig. 3. Quality and safety control system of dairy supply based on the combination of HACCP & GS1

7. CONCLUSION

China's dairy industry has developed very rapidly for the past few years, however, compared to developed countries in Europe and America it still has many weaknesses, for example, specialized, systematized, and informationalized cold-chain system has not been formed yet. Therefore, accelerating the construction of cold-chain facilities such as special refrigeration storage, refrigeration truck, temperature controlling equipment, etc; regulating the CCP system in the dairy supply chain processes; increasing investment in information construction of the dairy supply chain for realizing information sharing and tracing in the whole supply chain, are badly needed for the development of China's dairy supply chain in the future.

As an integrated system, total utility of the entire supply chain can be impacted by the error of a certain link. Therefore, the quality and safety control system which is proposed in this paper is an effective way to guarantee the safety and quality of the dairy product. For one thing, it could supervise, analyze and control safety hazards for every links of the supply chain, and for another, it could regard supply chain as an information chain, in consequence, all the factors which could impact the safety of the food can be shared, tracked, located, and analyzed immediately. This system could not only ensure the safety and quality of the dairy products, but also constantly improve and optimize the system itself. In future studies, the flow of HACCP would be more and more meticulous and standardized, and meanwhile, with the rapid development of information technology, food quality and safety control system would be more widely and conveniently applied in the food industry. It could definitely improve the quality and safety of the food products, and rebuild the confidence of customers in China's dairy market.

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Paper 2: An Agri-food Supply Chain Traceability System for China Based on RFID & Blockchain Technology

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An Agri-food Supply Chain Traceability System for China Based on RFID & Blockchain Technology

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ABSTRACT

For the past few years, food safety has become an outstanding problem in China. Since traditional agri-food logistics pattern can not match the demands of the market anymore, building an agri-food supply chain traceability system is becoming more and more urgent. In this paper, we study the utilization and development situation of RFID (Radio-Frequency IDentification) and blockchain technology first, and then we analyze the advantages and disadvantages of using RFID and blockchain technology in building the agri-food supply chain traceability system; finally, we demonstrate the building process of this system. It can realize the traceability with trusted information in the entire agri-food supply chain, which would effectively guarantee the food safety, by gathering, transferring and sharing the authentic data of agri-food in production, processing, warehousing, distribution, and selling links.

Keywords - Agri-food supply chain; traceability system; RFID; blockchain; food safety

1. INTRODUCTION

With the vigorous development of China's economy, people's standard of living has been improved constantly, which changed the consuming habit of the consumer, and more and more attention is paid to food safety and quality. However, in recent years, a series of serious food safety accidents occurred one after another, even in Europe there was a "horsemeat scandal" in 2013 (Boyacia et al., 2014) [1]. It's worth noting that these kinds of scandals are even more frequent and serious in China, such as "Sudan red", "clenbuterol", "Sanlu toxic milk powder" and "trench oil" [2], which harm people's health and destroy their trust in domestic food markets. These scandals not only deeply influence the normal development of the economy, but also endanger the stability and security of the society. As a large agricultural country, the annual demand for fruits and vegetables is around 730 million tons in China [3]. Since these agri-foods are highly perishable, their requirements for the temperature and humidity of the environment in logistics process are very rigorous. However, in reality, due to the backward agri-food logistics system, the agri-food loss ratio is up to 25% to 30% per year in China. At the same time, in the developed countries in Europe and America, their agri-food loss ratio is normally less than 3% (Zhang, 2011) [4]. Furthermore, because of the out-dated logistics systems and too many inefficient logistics links, the logistics cost normally accounted for around 70% of the total cost of the agri-food in China. However, according to the international standard, food logistics cost should never exceed 50% of the total cost (Shang et al., 2010) [5]. Currently, although they have been developing real rapidly in recent years, generally speaking, Chinese agri-food supply chain systems are still at the primary stage, and there are still many problems, such as the shortage of modern equipment and funds, low level of information application, disordered regulatory systems, and the lack of the monitor-able traceability systems. Due to these reasons, food safety events have broken out frequently and massively in China, which makes consumers to be the vulnerable groups in the markets. Obviously, these primitive and inefficient logistics systems can not guarantee the quality and safety of the food products anymore.

Based on the reasons above, the primary purpose of this paper is to establish an agri-food supply chain traceability system based on RFID and blockchain technology for helping Chinese agri-food markets to enhance their food safety and quality, at the same time, to significantly reduce the losses during the logistics process. The remainder of the paper is organized as followed. We begin with a brief overview of existing literature on the application of RFID and blockchain technology in agri-food supply chains in section 2.

Then we simply introduce the RFID and blockchain technology, and demonstrate the conceptual framework of the agri-food supply chain traceability system in section 3. In section 4, we compare traceable agri-food supply chain with the traditional one, and analyze the advantages and disadvantages of using RFID and blockchain in agri-food supply chain traceability system. After that, we demonstrate the building process of the agri-food supply chain traceability system model in section 5. Finally, we make a brief conclusion for this paper in section 6.

2. LITERATURE REVIEW

Agri-food supply chains have been extensively studied. For example, Li et al. (2006) [6] developed a dynamic planning method for agri-food supply chain. This method attempts to minimize the losses of agri-food products while simultaneously maximizing the profits for agri-food supply chain members. By using an analytical model, they demonstrated that real-time product information which passes through the agri-food supply chain could be valuably used. Many other researchers have put more efforts to the agri-food quality and safety. Trienekens & Zuurbier (2008) [7] insisted that government departments should respond for ensuring the quality and safety of agri-food products by setting legislation and regulations. In order to restore consumer confidence in the wake of kinds of scandals, many measures are also being taken, such as implementing production protocols, applying information technology in supply chain management processes to guarantee the quality and safety control through the transparency of the agri-food supply chain management (Akkerman et al., 2010) [8].

Several other researchers considered the application of advanced technology, especially RFID technology, in supply chain management. Sari (2010) [9] developed a simulation model for supply chain firm to find out under what kinds of conditions the investing in RFID technology is more beneficial for the firm. The study results show that using RFID technology in a supply chain will provide more benefits when the collaboration among supply chain members is more intensive. And these benefits are greater when lead-time is longer and the demand uncertainty of the market is lower. Wang et al. (2010) [10] proposed a rule-based decision support system to fulfill the real-time monitoring of agri-food products during their distribution process. Based on the information transmitted by sensor-RFID equipments from the refrigerated containers, this system calculates the remaining value and shelf-life time of agri-food products in transmission. Ustundaga & Tanyasb (2009) [11] presented a simulation model to obtain the expected profits of using a

RFID-based system in a supply chain by calculating the performance increasing in efficiency, security, accuracy and visibility. Their study shows how the product value, lead-time and demand uncertainty of the market influence the performance of the RFID system in the supply chain.

Among these researches, food traceability management has drawn more and more attention. It is defined by the European Union Commission as "the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution" (European Commission, 2002) [12]. Golan et al. (2004) [13] established a tracking and traceability system by using RFID technology to effectively monitor the key information of the whole food supply chain. Once there is an accident happening, the relevant questions can be immediately traced and tracked, which could ensure the food quality and safety. Aimed at the needs of the tracking and traceability in supply chain management, Li et al. (2010) [14] proposed the RFID-based logistics tracking and tracing model, and defined 5 different kinds of RFID business events. Besides, they also design the network structure, functional framework and security systems of the logistics tracking and tracing system. Taking agri-food as a research object, Yang et al. (2008) [15] built a security management and quality traceability system of vegetable production from the perspective of information technology, and demonstrate its main functions, operational process and key technology of this system.

Since most agri-foods are very perishable and their shelf-life time can be seriously influenced by temperature and humidity in logistics processes, refrigerated containers which are used to transport agri-food products could affect their quality and safety to a large extent (Montanari, 2008) [16]. Jedermann & Lang (2009) [17] developed the spatial temperature profile in refrigerated trucks and containers, which rely on RFID and sensor technology to automatically record and transfer the information of the transport environment (e.g., temperature, humidity) in the distribution process. Several available tracking and tracing technologies for this application are also evaluated and compared in their study.

Currently, a new technology called blockchain has drawn much attention from researchers in many different domains. The first application of the blockchain technology was Bitcoin, a peer-to-peer electronic cash system [18]. Beyond its initial application, blockchain has been generalized and researched in some different domains. Kosba et al. (2015) [19] presented a decentralized smart contract system: Hawk. Unlike other existing decentralized block chain systems in which all the transactions are exposed clearly on the block chain, "hawk" does not store financial transactions clearly on the block chain, thus retaining transactional privacy from the public's view. Bruce (2013) [20] proposed a purely P2P crypto-currency scheme with the "mini-blockchain". In their research they defined the "mini-blockchain", "proof chain" and "account tree", and described how these three mechanisms work together to built a system that can provide a high level of integrity and security, yet was much slimmer than all other purely P2P currencies. Beyond that, this system also has many other advantages such as faster transactions and lower fees, quicker network synchronization, support for high levels of traffic, more block space for custom messages, and increased anonymity. Foroglou et al. (2014) [18] introduced the blockchain technology and the background of Bitcoin. Furthermore, they showed that how blockchain technology can be advantageously used in different domains, such as the currency, contracts, voting, intellectual property rights, smart property and finance, in the future.

According to the discussion above, many studies have considered the use of RFID in agri-food supply chain management. However, most of them concentrated on technical functions of RFID and its integrated application with other technologies, such as WSN (Wireless Sensor Network), GPS (Global Positioning System) and GIS (Geographic Information System), etc. Besides, instead of covering all stages of the supply chain management, most studies only considered distribution and warehousing steps. Another important question they have not considered is that whether the information shared by supply chain members in the traceability systems can be trusted. Therefore, as far as I know, there is a lack of published literature that studies the use of RFID technology to establish a traceability system for guaranteeing the quality and safety of the agri-food product in the whole supply chain, which includes production, processing, warehousing, distribution and sales. Further more, there is no published paper that proposes using blockchain technology to solve the issue of information credibility in agri-food supply chain traceability systems. Instead of storing data in a silo, with blockchain technology all the information of the agri-food products can be stored in a shared system for all the members along the supply chain. In this paper, an agri-food supply chain traceability system based on RFID and blockchain technology is developed, and the details of its implementation process in every supply chain link are demonstrated. This system can effectively improve the efficiency and reliability of agri-food supply chain management and significantly strengthen the quality and safety of agri-food products, especially in today's China's markets.

3. CONCEPTUAL FRAMEWORK OF THE AGRI-FOOD SUPPLY CHAIN TRACEABILITY SYSTEM

3.1 Introduction of RFID

RFID (Radio Frequency Identification) is a non-contact automatic identification communication technology. It can automatically identify multiple, high-speed moving objects simultaneously even under poor environment and without manual intervention. Moreover, it can tag, save and manage information of objects through a radio-frequency signal. Compare to bar code, RFID tag technology has a lot of advantages, such as convenience, antipollution, mass-capacity information and recyclable.

In the logistics area, RFID has been widely used in production-processing, warehouse management, logistics tracing and product anti-fake, etc. With the extensive applications of RFID, the level of supply chain management has been highly improved. Over the years, more and more attention has been paid to the development and application of RFID in many countries. As the leader of RFID technology, from setting the standards to develop relevant software and hardware, the USA always be advanced than other countries. The RFID standard of the EU is just following the American EPC global standard, and in application area they are basically at the same developmental stage. Furthermore, relying on the domestic enterprises, Japan established a UID (Ubiquitous ID) standard. The development of Chinese RFID technology started relatively late, but it developed very fast in recent years and has been extensively applied in many areas, such as logistics, catering, retail, manufacture, medical treatment, identification and payments.

3.2 Application of RFID technology in agri-food supply chain

Agri-food supply chains including production (planting/feeding), picking/slaughter, processing, warehousing, distribution and sales. In these series of links, the value of the agri-food could be extremely improved by strictly guaranteeing the quality and safety of the agri-food. In agri-food supply chain, RFID technology is mainly applied in processing management, warehousing management, distribution management and traceability management. Early in 1998, “Cattle tracking systems plan” had been implemented in Britain. In this plan, RFID electronic ear tag is used for tracking and identifying livestock like cattle, sheep, horse and pig during their raising stage. And in January 2008, European Union passed legislation to pressure livestock farm to use electronic identification for sheep (Peng et al., 2011) [21]. In USA and Japan, RFID system had been used for tracking agri-food in the entire supply chain from planting to the distributor and retailer. In these supply chain processes, RFID systems provide management information and safety data of agri-food for producer, wholesaler, retailer and consumer. During the 2008 Beijing Olympic Games, RFID technology had been used for tracking and monitoring the Olympic food. Athletes and staff could get the information about the food they eat, including what kinds of food they have eaten; where are these foods come from; and what processes these foods have gone through, by their personal RFID ID card (Liu et al., 2012) [22]. By using RFID technology, agri-food supply chain management could realize the tracing and monitoring of “from farm to fork”, and once the food safety issues happen we can find their source and solve the problem immediately.

3.3 Introduction of blockchain technology

Generally speaking, the validity of information relies on the trusting in the centralized unit of the system or the powerful third-party organization. However, there is an information asymmetry between the organizations and the individuals, and once such monopolizing “centralized organization” becomes a vulnerable target for bribery or targeted hacking, for example the administrator can be bribed, the real and valid information can be tampered with, then the whole system can not be trusted any more. Thanks to blockchain technology, this kind of problem can be perfectly solved.

The essence of the blockchain is a technical scheme of reliable database which is collectively maintained by the way of decentralized and trustless method. This technical scheme could create blocks through any number of the nodes in the system by using cryptography. It is just like what the name says: a chain of blocks. Each block contains the data of all transactions in the system within a period of time, and it could create digital fingerprinting which can be used to verify the validity of the information and connect with the next block [20]. There can be a huge number of such blocks in the blockchain. The blocks are linked to each other in a linear (like a chain), chronological order with every block containing a hash of the previous block.

The blockchain technology can be visualized as a general term for technical schemes which are similar to NoSQL (Not Only Structured Query Language), and it can be realized by many kinds of programming languages. Currently, there are some methods for achieving that, such as POW (Proof of Work), POS (Proof of Stake) and DPOS (Delegate Proof of Stake).

According to the definition of the blockchain above, a blockchain-based system should have several features: decentralized, trustless, collectively, reliable database and anonymity.

Decentralized: there is no organization in the whole network, and even if a node is crashed, the whole system will still be up. Therefore, the blockchain system is very robust.

Trustless: since the whole system is running transparently, the system is absolutely open source and there is no need for trust among every single node and any node can never cheat other nodes.

Collectively Maintain: the blocks of the system are maintained by all the nodes in the whole system, and everyone can become one node of the system after registering online.

Reliable Database: every node could receive a complete copy of the database from the system through the form of sub-database. Tampering with the database by one node is invalid, and that could not influence the data of other nodes, unless one can control over 51% of the nodes in the whole system at the same time. Thus, if there are more nodes in the system, it will be more secure.

Anonymity: since there is no need for trust between nodes, there is no need for nodes to reveal their identities and all the nodes in the system are anonymous.

The core problem solved by blockchain technology is how to create a trust-free environment for business and management activities in the situation of information asymmetry. This problem is known as "Byzantine failures", which means how we can build a consensus foundation for secure information transaction without worrying about data tampered when any nodes can not be trusted in the whole network. Blockchain could guarantee the security of the whole network by using mathematical algorithm mechanism [23]. Thanks to blockchain, all the nodes in the system could exchange their data autonomously and securely in the trustless environment.

3.4 The basic concept of agri-food supply chain traceability system based on RFID & blockchain technology

The agri-food we mentioned in this paper contains two types: fresh fruits & vegetables, and meats which include pork, mutton, chicken and beef. The agri-food supply chain traceability system which we build in this paper mainly relies on RFID technology to implement data acquisition, circulation and sharing in production, processing, warehousing, distribution and sales links of agri-food supply chain. Besides that, it also uses blockchain technology for guaranteeing the information which shared and published in this traceability system is reliable and authentic. This traceability system not only covers each enterprise in the agri-food supply chain, but also includes some compulsory food safety & quality supervision inspection centers, such as government departments and third-party regulators.

For example, government departments could use this system to check the safety status of the products at any time. Once the food safety accident happened, government departments could take emergency measures immediately to prevent the spreading of the hazard. Thanks to RFID & blockchain technology, this traceability system could realize the information identification, inquiry, tracking, monitoring and tracing for the whole supply chain, and it could also be a secure, transparent and traceable platform for all the members in the agri-food supply chain. In addition, excepting RFID & blockchain there are many other technologies which can be comprehensively used in this traceability system, such as WSN, GPS, and GIS, etc. For example, GIS can be used together with RFID to control and track the production of the plants. Meanwhile, GPS can be used to make the vehicle positioning and optimal distribution route for distribution vehicles. In conclusion, all of these great features enable this new traceability system to effectively guarantee the safety and quality of the food, and implement the precise recalling and responsible investigation for the defective product.

4. ADVANTAGES AND DISADVANTAGES OF THE AGRI-FOOD SUPPLY CHAIN TRACEABILITY SYSTEM BASED ON RFID & BLOCKCHAIN TECHNOLOGY

4.1 Comparative analysis between centralized traceability system and RFID & blockchain based traceability system

4.1.1 Traditional agri-food supply chain

The traditional agri-food supply chain mainly includes raw material supplier (seed, fertilizer, fodder, etc), producer (farmer), agri-food processor, logistics enterprise, wholesaler and retailer, consumer. In this supply chain, the information transferring of agri-food is synchronized with its logistics delivery, the former attached to the latter, which means it is a unidirectional linear information transfer system. However, processing technical of modern agri-food product has become more and more complex, and the same goes for its circulation links. Therefore, it is difficult to implement safety trace management of agri-food relying on the traditional agri-food supply chain pattern. Furthermore, this unidirectional linear information flow could easily cause the postponement and distortion of information, which would aggravate the occurrence of agri-food safety issues and increase the cost of safety supervision administration.

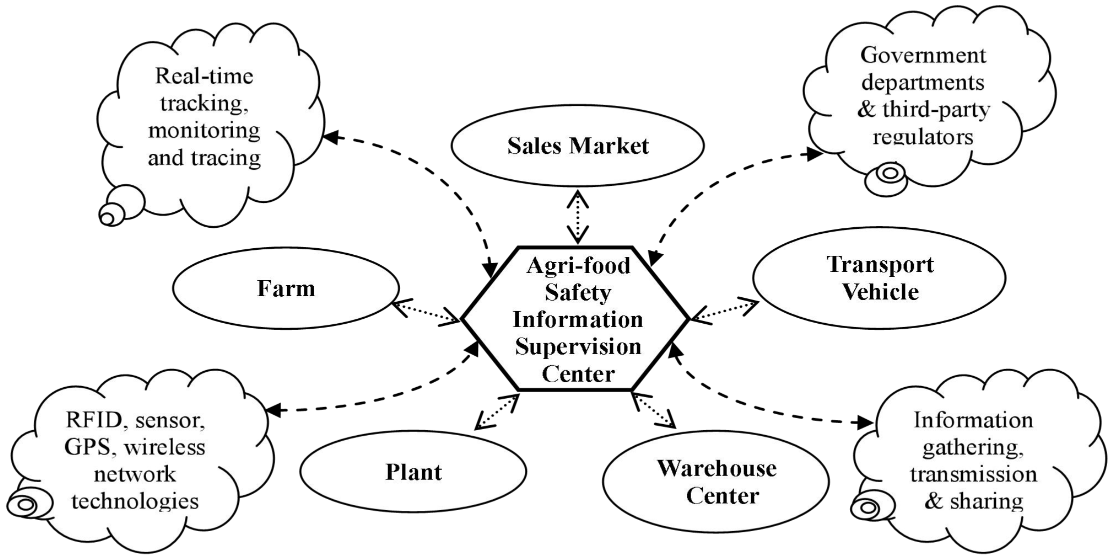

Fig. 1. Conceptual framework of centralized agri-food supply chain traceability system

4.1.2 Comparison between centralized traceability system and RFID & blockchain based traceability system

Fig. 1 shows the framework of a centralized agri-food supply chain traceability system which has been widely used recently. There is not much difference between the main constituent parts of this centralized traceability system and the traditional one, but it is quite advanced for information transferring and handling in a traceability system. In this system, supply chain members rely on an information supervision center to transfer and share their information, which fulfills the informatization and intelligentization of agri-food in the processes of production, processing, warehousing, distribution, sales and traceability management. This centralized traceability system thoroughly changed the unidirectional linear information transfer mode of traditional agri-food supply chain, effectively implements the information sharing and, to some extent, realizes the traceability management in the whole agri-food supply chain.

However, as said above, this centralized format has many weaknesses. The biggest problem is that it is a monopolistic, asymmetric and opaque information system, which could result in the trust problem, such as fraud, corruption, tampering and falsifying information. As is shown in Fig. 2, our new traceability system which has applied blockchain technology could obviously solve these issues of centralized organization. In this system, instead of being an information supervision center, government departments and third-party regulators are just some normal nodes of the system, just like all the other members of the system. However, they also have their own responsibilities, such as forcing the application of RFID in the entire agri-food supply chain, and inspecting the authenticity of the information uploaded by supply chain members. By using RFID & blockchain technology, this new decentralized traceability system could become a disruptive innovation which could increase the transparency of the supply chain, strengthen the information credibility, realize the real-time tracking of agri-food, and consequently, enhance the safety assurance of the agri-food supply chain.

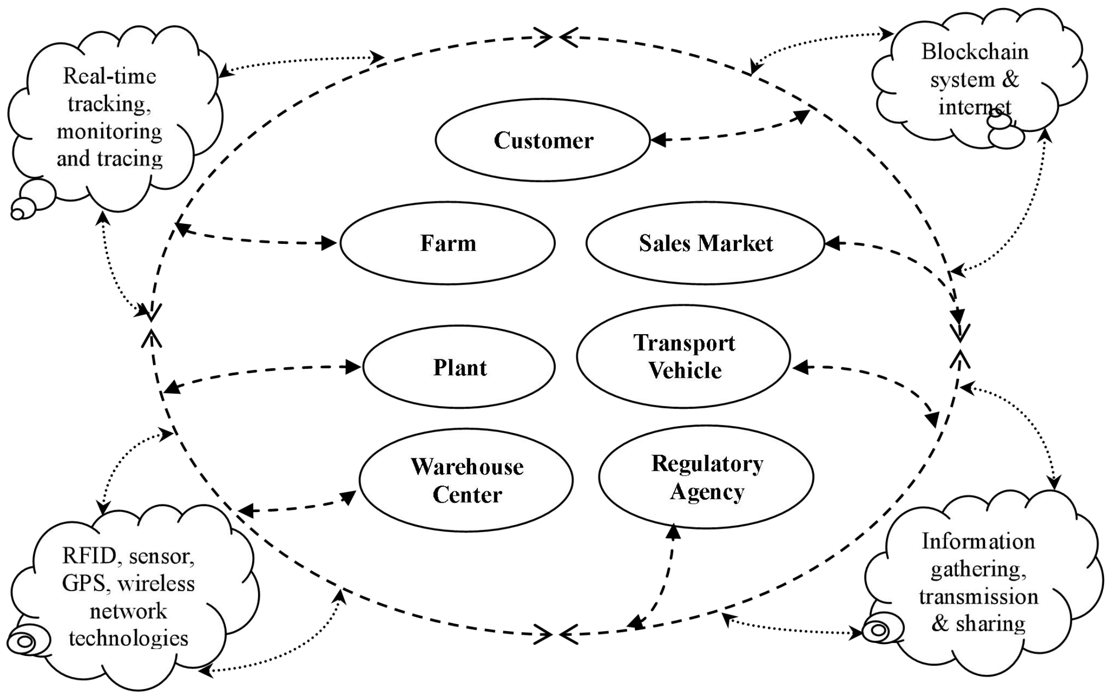

Fig. 2. Conceptual framework of an agri-food supply chain traceability system based on RFID & blockchain technology

4.2 Advantages of the agri-food supply chain traceability system based on RFID & blockchain technology

4.2.1 Benefit to tracking and traceability management

Agri-food supply chain traceability system builds a kind of agri-food information chain which covers the food safety supervision regulators, farms, livestock farms, processing enterprises, logistics enterprises, sales enterprises (supermarket) and customers. Moreover, relying on the blockchain system, all the information of the agri-food in the supply chain is transparent and open, thus logistics enterprise could implement real-time tracking for the agri-food products, supervision regulator could execute traceability management and responsibility investigation for defective product, consumer could obtain the full information of the products in the entire agri-food supply chain, which are beneficial to establish a healthy market environment.

4.2.2 Benefit to reducing the agri-food losses and logistics cost

Facing the huge loss of agri-food caused by China's underdeveloped logistics system, only to integrate the agri-food industry chain between upstream and downstream enterprises and improve the information acquisition and sharing degree in the supply chain by establishing an agri-food supply traceability system can enhance the agri-food logistics efficiency and extremely reduce the loss and logistics cost.

4.2.3 Benefit to enhance the credibility of the agri-food safety information

Currently, most of the RFID-based supply chain traceability systems are all based on the idea of using a centralized system with the government department or a third party organization to achieve information transparency along the supply chain. However, these kinds of centralized organizations are completely opaque and the user will never be able to know the inner details of the transactions. This could lead to information fraud and extortion for supply chain members. A new traceability system which contains blockchain technology removes the need for a trusted centralized organization and provides an information platform for all the members in it with openness, transparency, neutrality, reliability and security.

4.2.4 Benefit to fighting against the counterfeit and shoddy products

The information data of the product could be encrypted and protected by binding the product with a unique ID of RFID tag, which could protect the product from counterfeited. Moreover, by applying RFID, many kinds of agri-food information can be added into the traceability system through intelligent equipment. Since this process does not need any manual operation, greatly decrease the mistakes caused by human factors. Besides, by using blockchain technology, all the members in this system are unable to manipulate agri-food information, which further increases the safety and quality of the product.

4.2.5 Benefit to improve the international competition of Chinese agri-food exports

Chinese backward agri-food logistics systems which lack traceability can not guarantee the safety and quality of agri-food, and significantly reduce international competition of Chinese agri-food. However, using RFID & blockchain technology could realize safety supervision and traceability management for agri-food in the whole supply chain, which can not only increase the circulation efficiency of agri-food and strengthen its quality and safety assurance, but more important, since this traceability system saves huge amounts of data about agri-food, production sales enterprises could make their market demand analysis, production and sales plan based on these data information.

4.3 Disadvantages of the agri-food supply chain traceability system based on RFID & blockchain technology

4.3.1 The high cost

First of all, the cost of RFID tag is very high. Comparing with barcode, the minimum cost of RFID tag is 0.3 dollar, however, in China a barcode normally cost only 0.02 RMB (Zhang et al., 2014) [24]. Because of Chinese relatively lower labor costs, facing so exorbitant price many enterprises are not interested in RFID technology. Secondly, establishing this kind of agri-food supply chain traceability system needs a series of corollary equipments, various kinds of hardware and software, upgrading and transformation of the original logistics systems, personnel training cost. In consequence, all of these conditions seriously restrict the application and popularization of RFID technology in the logistics area.

In order to reduce the cost, many enterprises try to narrow the application scope of RFID. For instance, instead of using RFID tag on every single product, it can be mainly used on pallet, packing-case, and container, etc. Meanwhile, for a single product, barcode can be used to greatly lower the cost. These two solutions, to some extent, could solve the problem of high cost for applying RFID technology in the logistics area. Another way to reduce the cost of RFID is to realize the large-scale application. However, enterprises will not invest in it if there are not enough returns. Actually, for these high-quality products where a marginal increase of some degree to the price would not affect the willingness of the customers to buy, which means customers maybe would rather pay more for these products for safety and reliability. Besides that, using RFID could extremely improve the production and management efficiency, which is also a kind of benefit and advantage to enterprises.

However, in nowadays China's markets, investment for RFID application is mainly from the upstream enterprises in agri-food supply chain, but the benefited party normally is the downstream enterprises. Therefore, how to solve the problem of costs and benefits sharing among supply chain members is the key to facilitate the large-scale application of RFID technology in the future.

4.3.2 The lack of unified technical standard

The industry standard of RFID includes frequency division, coding rules, etc. So far, since there is no unified international standard for RFID, international standard organizations ISO (International Standardization Organization), IEC (International Electro technical Commission), ITU (International Telecommunication Union) and UPU (Universal Postal Union) are all trying to build a unified international RFID standard (Deng et al., 2011) [25].

4.3.3 The immaturity of blockchain technology

As an emerging technology, blockchain is still in its initial phase and there are some obstacles to its further application. For instance, right now the transaction capacity of blockchain is restricted to 7 transactions per second due to the restricted size of block, while VISA can handle up to 47000 transactions per second [20][26]. Another obstacle is how to deal with the ever-growing size of the blackchain for the issues as storage and synchronization. On an average, every ten minutes, a new block is appended to the blockchain through mining [18].

5. THE BUILDING PROCESS OF THE AGRI-FOOD SUPPLY CHAIN TRACEABILITY SYSTEM BASED ON RFID & BLOCKCHAIN TECHNOLOGY

In this section, we will demonstrate the information journey of agri-food products through the whole supply chain within our new traceability system.

5.1 Production link

In production stage, for plant products, RFID tags are mainly used on their packaging, which save many kinds of information of agri-food product including the variety, name, producing area, planting time, fertilization condition, usage of pesticides, plucking time, etc. For the meats products, such as pig, RFID ear tags are normally used to save the information of the pig, including the information of its parents, fodder, epidemic prevention checking and medication situation, from birth to slaughter. Moreover, these RFID tags also record the information of production managers and operational staff, and once the food safety accident happens the relevant managers and staff can be found and to deal with the accident immediately. All relevant information which is saved in the RFID tag can be uploaded to the blockchain system through the wireless network. Therefore, in other links of the supply chain, this information can be directly obtained by the RFID reader or checked by accessing the data on the blockchain through the tag at any time.

5.2 Processing link

After receiving agri-food products from production enterprises, processing enterprise could understand the basic information of products by scanning their RFID tags, and update their information in the RFID tag after finishing the processing flow. For the plant products, like the production link, RFID tags are used for the agri-food products which have relatively high value and strict requirement for environment; for these products with low value, RFID tags are only used on their pallets and packing-cases, and the barcodes are mainly used for the single agri-food products. For the meat products, taking pigs as an example, the information, such as the source, number, receiving date and epidemic prevention should be written into the RFID tag. The RFID tag which is bound with animal product could also record the information in its processing stage such as product type, weight, expiration date, storage conditions, inspection and quarantine information, etc.

Since the agri-food processing link is a very complicate stage which is the key to the safety and quality of the agri-food product, the updated information in the RFID tag should also include the situation of using additives, the basic information of processing enterprise and relevant staff. And then again, upload this updated information to blockchain system, which can be conveniently inquired by all the members among the agri-food supply chain.

5.3 Warehousing management link

By setting up relevant RFID equipment in warehousing center, the information of received products, storage environment, agri-food’s receiving and delivery time can be automatically obtained. Meanwhile, with wireless sensors and monitoring equipment, the RFID reader can be used to directly query inventory information. And all relevant information should be saved in blockchain system, and opened to all the members in the system.

The application of RFID technology could not only greatly improve the efficiency of warehouse management, but also fulfills the enterprise’s requirement for dynamic storage management which could enhance the quality and safety of stored products as well. First of all, information in the RFID tag can be used to query agri-food product’s information such as quantity, category and storage time, etc. Secondly, in order to avoid loss and spoilage, based on the product quantity and storage time, managers can make decision for which products should be given priority to move out of the storage. Finally, RFID systems can be also used to check the real-time environmental information of cold storage, including temperature and humidity, which could avoid food safety accident occurring.

5.4 Cold chain distribution link

In the distribution process, 3T principle (Time, Temperature and Tolerance) is the key factor in ensuring the safety and quality of agri-food. According to different temperature requirement, refrigerated truck can be divided into several areas, which can be easily used to store different type of agri-food. In addition, a vehicle-mounted safety monitoring system can be established by setting temperature and humidity sensors in different temperature areas with vehicle-mounted wireless network and computer. This small system allows delivery staff to transfer the temperature and humidity real-time data of agri-food to blockchain system. Meanwhile, when the temperature and humidity exceed the security standard the vehicle-mounted safety monitoring system will immediately raise the alarm. Last but not least, by using GPS, distribution center could implement vehicle positioning for each refrigerated truck and make the optimal distribution route for them to shorten distribution time, which could guarantee the freshness of the agri-food.

5.5 Sales link

(1) **Information tracing**. Since RFID tag saved the information of agri-food in the entire agri-food supply chain, once food safety accident happens, the defective products can be located immediately. Moreover, happening reasons, location and responsible staff can be traced by blockchain system as well, which could extremely reduce the losses and hazards.

(2) **Guarantee the freshness of products**. Due to the short freshness lifetime of agri-food, RFID system can be applied to monitor the freshness lifetime of products. Therefore, sales enterprise could replace these agri-food products which are close to their expired time.

(3) **Transparency of product information**. When consumers are shopping in the supermarket, they can use the RFID reader to obtain the basic information of agri-food products by scanning their RFID tags. Moreover, thanks to blockchain technology, all the information along the agri-food supply chain is fully auditable, which means customers could also obtain details information about the final products in a real-time manner by inspecting the blockchain system. Besides that, due to the strong integrity properties of the blockchain, this information can be genuinely trusted [23]. By using RFID & blockchain technology, transparency of products information could significantly enhance the

consumers' trust for quality and safety of agri-food products and obviously increase their confidence for the agri-food markets.

6. CONCLUSION

In this paper, an agri-food supply chain traceability system is established, based on RFID & blockchain technology, combined with WSN, GPS, GIS and computer data processing technology, etc. This system covers the whole process of data gathering and information management of every links in agri-food supply chain, which realizes the monitoring, tracing and traceability management for the quality and safety of the agri-food "from farm to fork", and effectively guarantee the quality and safety of the agri-food products. In future studies, with the rapid development of blockchain technology, building a decentralized traceability system in which the information can be completely trusted is the development tendency of the logistics industry. And if the application cost can be significantly reduced and its technical standard can be unified, RFID technology will be more widely used in the logistics industry, especially in agri-food logistics industry. There is no doubt that with the application of these emerging technologies, products can be understood, carried, checked and trusted as they travel along the supply chain. This will effectively enhance the quality and safety of agri-food products.

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Paper 3: A Supply Chain Traceability System for Food Safety Based on HACCP, Blockchain & Internet of Things

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A Supply Chain Traceability System for Food Safety Based on HACCP, Blockchain & Internet of Things

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ABSTRACT

In recent times food safety is an increasing academic and commercial concern. In particular, the food supply chain has seen various innovations of traceability systems based on emerging internet technologies. However, to date, these systems are typically centralized with a monopolistic, asymmetric and opaque structure. This often brings up issues of trust, whether these systems could become subject to fraud, corruption, tampering and falsifying information. In addition, a centralized system is vulnerable as a single point of failure. Today, a new technology called the blockchain building on a decentralized information technology offers completely new features. However, since this technology is still in its early stages, it faces challenges in terms of scalability. In this paper we will build a food supply chain traceability system for real-time food tracing based on HACCP (Hazard Analysis and Critical Control Points), blockchain and Internet of things, which could provide an information platform for all the supply chain members with openness, transparency, neutrality, reliability and security. Our work builds on the concept BigchainDB to fill the gap in the decentralized systems at scale. The paper concludes with a description of a use case and the challenges to adopt blockchain technology in the future food supply chain traceability systems are discussed.

Keywords - Food supply chain; traceability systems; decentralized systems; blockchain; food safety

1. INTRODUCTION

Food touches everyone and everywhere. During the last couple of decades, customer confidence in the food industry was heavily destroyed after lots of food safety risk incidents and scandals, such as mad cow disease, genetically modified food (Aung & Chang, 2014) [1], toxic milk power, and trench oil (Xiao et al., 2012) [2]. As a consequence, further increasing consumer concerns over the safety and quality of food have drawn more and more attentions from academic and industrial areas. In response to growing food safety issues, many internet of things technologies, such as RFID and wireless sensor network-based architectures and hardware, are applied to supply chain traceability and visibility. However, there is a very important issue has not been touched is that whether the information shared by food supply chain members in the traceability systems can be trusted. Generally speaking, relying on one single authority organization to control all sensitive and valuable information needs a great deal of trust. This kind of centralized organization could become so powerful by possession of this data that could result in information asymmetry between the organizations and the individuals. The centralized organization can become a vulnerable target for bribery, and if, for example, the administrator can be bribed, valuable information can be tampered with, and then the whole system can not be trusted anymore. This is exactly what is happening in China's food markets (see Sanlu toxic milk powder scandal). Another potential risk of the centralized system is that it becomes a single point of failure which leaves the whole system vulnerable to failure (e.g. hacking and corruption) [3]. The novel technology that could be the key to these issues is the blockchain, which can remove the reliance on a central entity. Instead of storing data in an opaque network system, with the blockchain, all the information of the food products can be stored in a shared and transparent system for all the members along the supply chain. As an emerging technology, blockchain has its inherent shortcomings, and with the increasing application, scalability has become a primary and urgent concern. In this paper, we will try to find a solution from the perspective of the blockchain and distributed database. We hope that our system could make food traceability from "farm to fork" become a reality, and rebuild public confidence in the food supply chain.

The paper is organized as followed. Section 2 presents the existing literature on the application of HACCP, RFID and blockchain technology in the food supply chains. Then a typical scenario for the food supply is presented, and relevant critical points are identified with HACCP in section 3. Section 4 introduces the details of the blockchain and smart contract, proposes a solution for blockchain scalability issues, and demonstrates the architecture and functions of our system. Through a use case, section 5 illustrates how the monitoring and corrective actions identified in section 3 can be supported by our system. Finally, we make a brief conclusion for this paper in section 6.

2. Background

In this section, we discuss the background of our research. First, we describe the general concepts of HACCP. Then, we discuss the application of traceability systems in the food supply chain. Finally, we highlight the importance of blockchain technology for the traceability problem.

The HACCP which focused on risk management and prevention was considered to be synonymous with food safety. It can be easily linked to operational management and food chain safety assurance. It was originally developed as a microbiologic safety system to assure food safety for astronauts by NASA in the 1960s (Bardic, 2001) [4]. Rather than other old food safety control systems which mainly rely on feedback control which is an inefficient approach and could result in huge loss, HACCP is a preventative method which could efficiently improve the level of food quality and safety (Bennet & Steed, 1999) [5]. In order to obtain high quality milk, Vilar et al. (2012) [6] implemented HACCP method on dairy supply chain, and they focus on the milk equipment and cooling tanks which could influence the milk quality by the hazards such as microbiological and chemical residues. They proved that implementation of HACCP can be a feasible strategy for dairy supply chain safety. Based on a Pareto analysis, Fotopoulos et al. (2011) [7] examined the literature on the food safety assurance systems and recorded the vital critical factors which affect the implementation of HACCP. In their research, they analyzed 31 studies and identified totally 32 factors that could affect HACCP implementation. By using a case study, Herath & Henson (2010) [8] pointed out four barriers to HACCP implementation, including perceptions which HAPPC is of “questionable appropriateness” to the company, the scale of change required to achieve implementation, low priority given to enhancement of food safety controls, and financial constraints.

With the rapid growth of internet of things, many researchers consider the application of relevant technologies for traceability systems in food supply chains. Folinas et al. (2006) [9] pointed out that the efficiency of a traceability system depends on the ability to track and trace each individual product and logistics units, in a way that enables continuous monitoring from primary production until final disposal by the consumer. Shanahan et al. (2009) [10] suggested a RFID based framework for beef traceability from farm to slaughter.

By using RFID for the identification of individual cattle, and biometric identifiers for the verification of cattle's identity, this system proposed as a solution to the inaccessibility of traceability records and the fraudulent activities. In order to build an automated system which integrates online traceability data and chill chain condition monitoring information, Abad et al. (2010) [11] tried to validate an RFID smart tag developed for real-time traceability and cold-chain monitoring of food under the case study of an intercontinental fresh fish logistics chain. Mattoli et al. (2010) [12] developed a Flexible Tag Data-logger (FTD) which is attached to the bottles for collecting environmental data, (like light, humidity, and temperature) in order to trace the wine bottles to a supermarket. The history data stored in the FTD can be read by smart phone or Personal Digital Assistant (PDA) with integrated infrared port to evaluate the safety status of wine bottles.

All the researches mentioned above are the idea of using a centralized system which was, until recently, the only conceivable way to achieve data and information transparency along supply chains. Today, a new technology called blockchain has presented a whole new approach and drawn much attention from researchers in many different domains. Abeyratne & Monfared (2016) [13] discussed the potential benefit of blockchain technology in manufacturing supply chain. They proposed that the inherited characteristics of the blockchain enhance trust through transparency and traceability within any transaction of data, goods, and financial resources. And it could offer an innovative platform for new decentralized and transparent transaction mechanism in industries and business. In addition, they also take manufacturing of cardboard boxes as an example to demonstrate how blockchain technology can be used in a global supply chain networks. As the lack of trust is a barrier for integration of business process across organizations, Weber et al. (2016) [14] insisted that blockchain could be an emerging technology for decentralized and transactional data sharing across a network of untrusted participants. They developed a technique to integrate blockchain into the choreography of processes in such a way that no central authority is needed, but trust maintained. Among these researches, some other researchers tried to solve the shortcomings, especially scalability, of blockchain. McConaghy et al. (2016) [3] described BigchainDB, which combine the distributed database (DB) with blockchain characteristics. Therefore, it has characteristics of distributed databases: linear scaling in throughput and capacity, efficient querying, and permissioning. And blockchain characteristics: decentralized, immutability, and creation & movement of digital assets. Croman et al. (2016) [15] analyzed fundamental and circumstantial bottlenecks of the blockchain for supporting substantially higher throughputs and lower latencies. Their results suggested that block size and intervals should be viewed only as a first increment toward achieving the next generation. In order to realize scalability, they discussed the techniques of blockchains from five planes, ordered in a hierarchy of dependency from bottom to top, Network, Consensus, Storage, View, and Side Planes.

According to the discussion above, internet of things has been widely used for supply chain traceability systems. However, most of them are centralized systems, and there are no decentralized systems have been used in food supply chains for food safety. In this paper, a decentralized information system is developed based on HACCP, blockchain and internet of things for food supply chain monitoring and traceability. Compare to the centralized systems, this new system could become a disruptive innovation which provides an information platform for all the supply chain members with openness, transparency, neutrality, reliability and security. Moreover, we also discussed the scalability of the blockchain technology when processing massive data within a business environment. We believe that our system could be a new perspective and idea for supply chain monitoring and traceability, and significantly enhance food safety in food supply chains.

3. FOOD SUPPLY CHAIN MODEL WITH HACCP

A typical scenario for the food supply chain is presented in Fig. 1, and associated with HACCP in different links are identified in Table. 1. As shown in Fig. 1, the whole food supply chain is divided into 5 links: A-Production; B-Processing; C-Warehousing; D-Distribution; E-Retail.

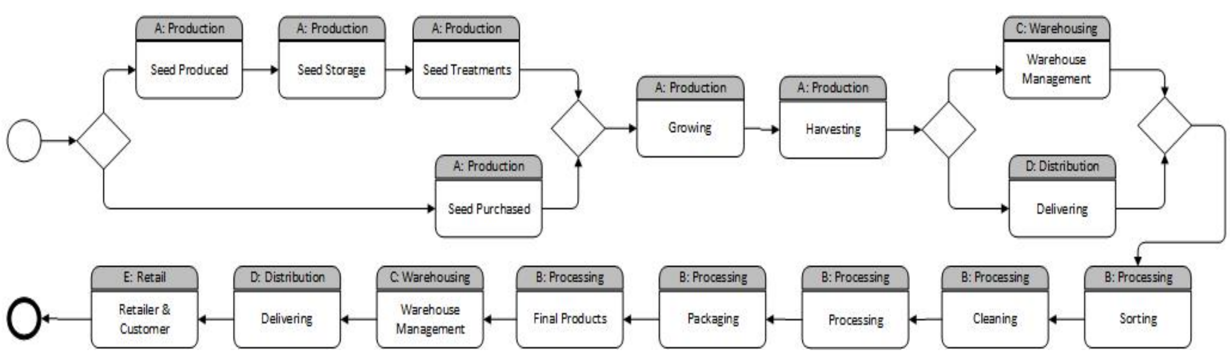

Fig. 1. Flow diagram for the food supply chain

Take crop plant production as an example. In the production link, first of all, background environment of planting should be assessed, including the quality of the soil, water, air, etc. Then all reasonable measures should be taken to ensure the quality of the seed. There are two sources of seed: previous harvested and purchase. For the former one, it should be treated prevent either spoilage or infestation. Therefore, potential control measures should be taken for such seed stocks. For the latter one, it should be purchased from a reputable supplier and relevant monitoring data should be requested [16]. In the processing link, processing is likely to take place at a different site. Consequently processing environment and equipment assessment will be required. All subsequent processing and packaging activities should be carried out according to good working practices. Besides, using additives and materials should be suitable for their intended purposes. In the Warehousing link, cold-chain equipment should be properly maintained. Moreover, all warehouse management practices (like recording environment of the cold storage, quality and storage time of products) should be according to good working practices. In the distribution link, all refrigerated equipment, like truck, should be properly maintained as well. Finally, in the retail link, all retail management practices (e.g., using the refrigeration; checking the freshness lifetime; replacing expired products) should be according to good working practices and recorded as a routine document.

Table 1. Typical hazard controls for the food suppl chain

Control	Hazard	Control Measures	Monitoring	Corrective Actions
A1	Safety risk from background environment	Site assessment as part of assured scheme (e.g., quality of the soil, water, air, sunlight)	Regulator approval; routine reassessment	Review site classification; Reassess site designation; document action taken
A2	Safety risk from seed	Seed produced according to accepted practices; seed purchased from reputable suppliers; seed passing the quality test	Regulator approval; site documentation; supplier documentation	Document actions taken; review supplier status
A3	Safety risk from field practices (growing)	All field practices according to good working practices and recording growing information (e.g., variety, item No, producing area, growth conditions, staff)	Site documentation	Review procedures; review workforce training; document actions taken
A4	Excess residues of applied fertilizers and pesticides	All applied fertilizers and pesticides purchased from reputable suppliers; recording the applied situation.	Regulator approval; supplier documentation; site documentation	Review supplier status; review producer; review workforce training; document actions taken
A5	Safety risk from	All field practices according to good	Site	Review procedures; review

	field practices (Harvesting)	working practices and recording harvesting information (e.g., planting time, plucking time, staff)	documentation	workforce training; document actions taken
B1	Safety risk associated with processing environment	Site assessment as part of assured scheme (e.g., temperature controlling, disinfecting, processing equipment)	Regulator approval; routine reassessment; site documentation	Review site classification; Reassess site designation; document action taken
B2	Safety risk associated with processing step	All processing practices according to good working practices, and process additives used for suitable for their intended purpose	Site documentation; supplier documentation	Review procedures; review workforce training; document actions taken; review supplier status; document actions taken
B3	Safety risk associated with packaging	All packaging materials and practices according to good working practices	Site documentation; supplier documentation	Review procedures; review workforce training; document actions taken; review supplier status; document actions taken
C1	Safety risk from site equipment	Ensure all equipment properly maintained (cold storage, temperature and humidity controlling systems)	Maintenance records	Review maintenance procedures; review workforce training; document actions taken
C2	Safety risk from warehouse management	All warehouse management practices according to good working practices (e.g., recording environment of the cold storage, quality and storage time of products)	Site documentation	Review procedures; review workforce training; document actions taken
D	Safety risk from site equipment	Ensure all equipment properly maintained (e.g., refrigerated truck)	Maintenance records	Review maintenance procedures; review workforce training; document actions taken
E	Safety risk associated with retail management	All retail management practices according to good working practices (e.g., using the refrigeration; checking the lifetime; replacing expired products)	Site documentation	Review procedures; review workforce training; document actions taken

4. THE TRACEABILITY SYSTEM BASED ON BLOCKCHAIN & INTERNET OF THINGS

4.1 Blockchain and smart contracts

Blockchain can be seen as a distributed database or ledger: a chronological chain of blocks and each block stores all information of network activity since the block is added to the chain [17]. All the data in the blockchain is public, and any user can add data to it in the form of a transaction which is identifiable data package in the system, any user can check and copy this data at any time, but it is prohibitively expensive to change it. Therefore, blockchain is an immutable history of network, which can be shared among all nodes on this distributed network. And the key feature of the blockchain-based system is that it removes the need for any centralized trust authority. Instead, trust is achieved through a so-called mining process which guarantees the security and validity of the information added to the chain among the nodes within the system.

In mining process, new transactions are verified by the nodes in the whole system known as "miners" before being added to blockchain. Miners add new blocks on the chain or new transactions on the block by a consensus algorithm, which must be confirmed by majority or all the nodes in the system, like a voting operation, as the valid data. Blockchain-based systems rely on miners to aggregate transactions into blocks and append them to the blockchain. Once the transaction is confirmed by a sufficient number of nodes, it becomes a valid and permanent part of the database [13]. In order to constantly validate and maintain the consistency data, the system rewards the miner for adding valid blocks to the chain by some form of digital credit like "gas" which is used to discourage over-consumption resources (During the execution of a transaction, every program instruction will consume some gas. Therefore, the user must pay some money for it). In this system, no single miner can change or add invalid data without being detected by other miners as a "bad actor". Moreover, the miner can not receive the reward if the relevant block is rejected. However, this block will be logged in the system, allowing the system to identify the miner as a potential threat. This method significantly enhances the transparency, trust, and traceability in a system.

A smart contract is a computer program that runs on the blockchain, i.e., executed by all consensus nodes. It consists of program code, a storage file. Any user can create a contract by posting a transaction to the blockchain. The program code of a contract is fixed when the contract is created, and can not be changed [18]. As shown in Fig. 2, the storage file of the smart contract is stored on the blockchain. Its program logic is executed by miners who reach a consensus on the outcome of the execution and update the blockchain accordingly. The code of the contract can be executed when it receives a message. The smart contract can read from or write to its storage file, while executing its code. Actually, the entire state of a smart contract is open to all the users in the system.

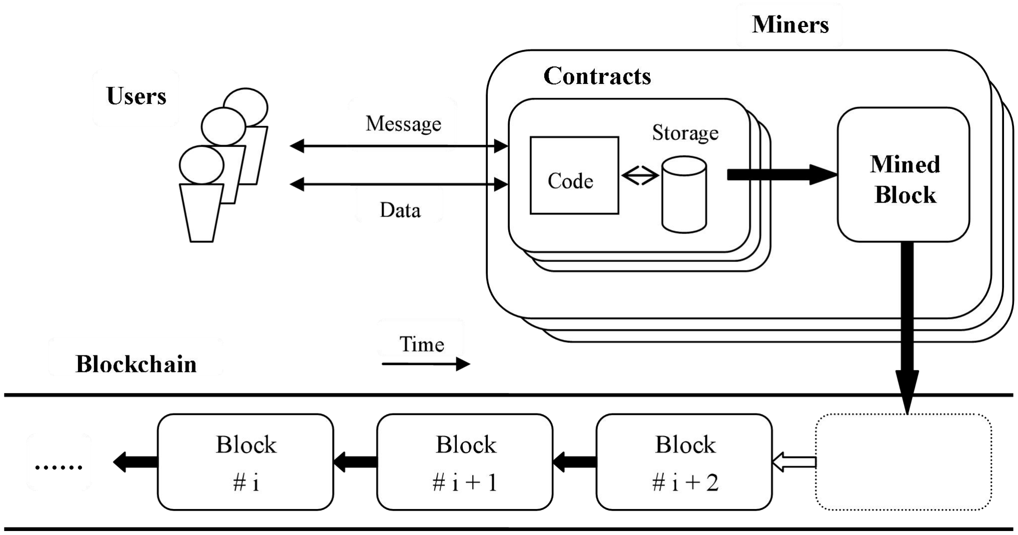

Fig. 2. Conceptual framework of a blockchain-based system with smart contracts

4.2 Scalability of the blockchain

As discussed above, the features of blockchain include “decentralized control”: no single entity can control the whole network; immutability: written data can never be tampered with; and “the ability to create & transfer assets”: remove the need for a central entity. These features can improve the security and transparency of decentralized systems. However, blockchain technology has scalability issues in terms of throughput, latency, and capacity when faces mass data in a real business environment.

Throughput: until now the throughput of the blockchain is restricted to 7 transactions per second due to the restricted size of block, while VISA can handle up to 47000 transactions per second [19]. This throughput is unacceptable low when considered to be used in a business environment.

Latency: each block on the blockchain needs 10 minutes to confirm a transaction. In contrast, it takes only seconds to confirm a transaction on the VISA system. Additionally, there is a negative correlation between throughput and latency.

Capacity: the whole Bitcoin blockchain is about 50GB in 2015. If its throughput increased to VISA's level, the blockchain database will grow 3.9GB/day [20]. Compared with normal distributed DBs which can store more than 1,000,000GB data, the data size of Bitcoin blockchain is really quite small. However, professional members still worry that it is growing too big.

According to the discussion above, advantages and disadvantages of distributed DBs and blockchains are highly complementary to each other. Therefore, we can try to solve blockchain scalability issues by giving it some distributed DBs characteristics. McConaghy et al. (2016) [3] proposed the concept of BigchainDB, which combines the key benefits of distributed DBs and blockchains.

As shown in Table 2, BigchainDB keeps three key characteristics of the blockchain. The decentralized control can be achieved through the nodes in the system with voting processing, which is known as a super-peer P2P network [21]. Immutability can be achieved by a chronological blocks in which each block holds an ordered sequence of transactions, and that is a block chain. Furthermore, any user can issue an asset with the asset-issuance permission and transfer an asset with the asset-transfer permission or the key of the asset. Therefore, it eliminates the risk of data tampering and single point of failure from hackers and powerful admins forever.

Table 2. Key characteristics of Blockchain, Distributed DBs & BigchainDB

	Blockchains	Distributed DBs	BigchainDB
High throughput	-	√	√
Low latency	-	√	√
High capacity	-	√	√
Decentralized control	√	-	√
Immutability	√	-	√
Creation & movement of digital assets	√	-	√

In addition, BigchainDB also leverages three key benefits of distributed DBs. The throughput of it can be increased with the number of nodes increased, and the scaling is a positive linear correlation: 10 × more nodes = 10c × more throughput, where $0 < c \leq 1$ [22]. In BigchainDB, each node stores data through the partial replication method, which means a node only stores a subset of all data, and each bit of data is replicated on several nodes. This method enables a positive linear correlation between the number of nodes and storage capacity, just like most modern distributed DBs. By comparison, capacity of blockchain-based systems will not change as the number of nodes increases.

4.3 Structure of the traceability system based on Blockchain and Internet of things

4.3.1 Overview of the traceability system

As shown in Fig. 3, the proposed system is a typical decentralized distributed system, which uses the Internet of things (like RFID, WSN, GPS) to collect and transfer, relies on BigchainDB to store and manage relevant data of products in food supply chains. There are many members among the supply chain, including suppliers, producers, manufacturers, distributors, retailers, consumers and certifiers. Each of these members can add, update and check the information about the product on the BigchainDB as long as they register as a user in the system. Each product is attached with a tag (RFID), which is a unique digital cryptographic identifier that connects the physical items to their virtual identity in the system. This virtual identity can be seen as the product information profile. Users in the system also have their digital profile, which contains the information about their introduction, location, certifications, and association with products.

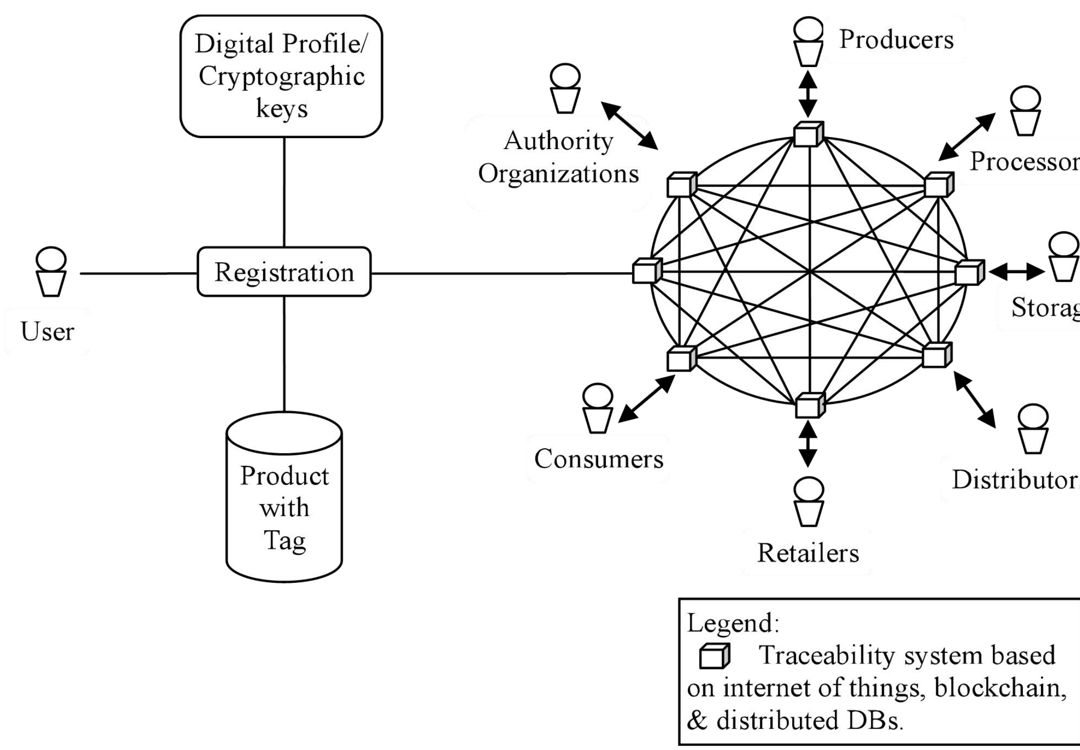

Fig. 3. Conceptual framework of the proposed traceability information system

All data in the system is stored in the BigchainDB and is opened to any user. The system is governed by a set of rules which are written in code and stored in the BigchainDB also. These rules define how users are to interact with the system, and how the data is shared among the users. Moreover, once the rules are stored in the BigchainDB, they can not be altered without broadcasting to all nodes and verified by most of them.

4.3.2 Registration and data updating & adding

Supply chain members can register themselves in the system as a user through the registrar, which can provide credentials and a unique identity to the members. After registration, a public and private cryptographic key pair will be generated for each user. The public key can be used to identify the identity of the user within the system and the private key can be used to authenticate the user when interacting with the system. This enables each product can be digitally addressed by the users when being updated, added, or exchanged to the next user in the downstream position of the supply chain.

In food supply chains, when a user who is in a particular link receives a product, only this user can add new data into the profile of the product with its private key. In addition, when user transfers this product to the next user, both of them have to sign a digital contract to authenticate the exchange. Therefore, the details of the transaction will be added to the BigchainDB and the system will process this data and update the information in the product's profile automatically, which allows users in the system sharing the status of the products at anytime.

4.3.3 Anonymity and sensitive information protection

Our system enables users on the supply chain to transfer and prove the defining attributes and status of their products to any user further along the supply chain. However, some users may want to keep some of their private information secret. Technologically, it is possible for our system to protect identities, while still transferring other important information. For example, producers in the supply chain can pass a digital contract with users from downstream while keeping their identity private. For consumers, maybe they only care about some important status of purchased products without necessarily knowing the full complication information of the whole supply chain that created them. As shown in Fig. 4, only some of the key control measures in table 1 are considered to be transferred and stored on the blockchain.

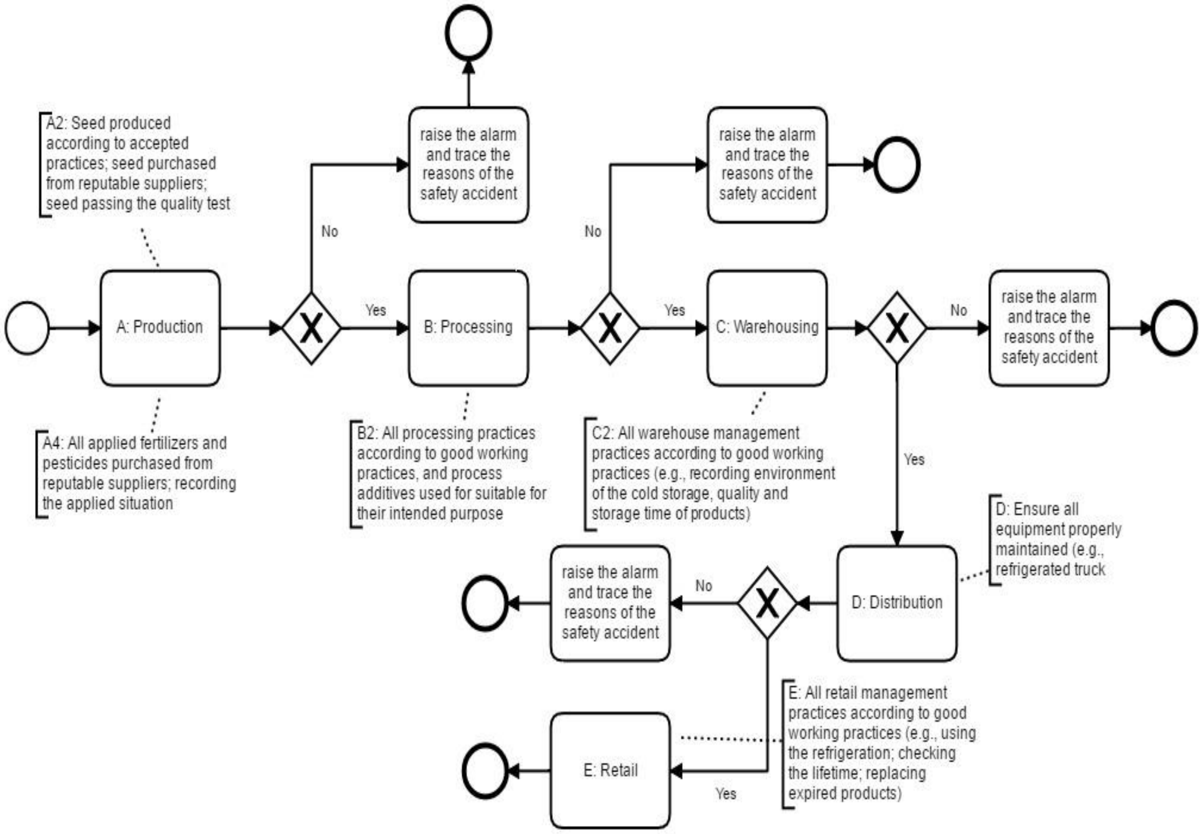

Fig. 4. Flow diagram of the food supply chain with key control measures in the critical control points

4.3.4 Role of the authority organizations

In our system there are still some certifications, audits, and third-party authorities, but the difference is that they also have to register and have a digital profile, and, they will take on a new guise implemented in the system. They will check and verify an user’s identity and behavior, and records the result in the BigchainDB, available for all to inspect. For instance, certifiers and third-party authorities will visit the factories or facilities to check and inspect whether relevant rules and regulations for standard programs are being met. Once verified by the authorities, the user’s profile and its products can be digitally updated and signed by the authority organizations. All the verification data must be published in the system, which extremely enhance the transparency of the supply chain and the safety of the food products.

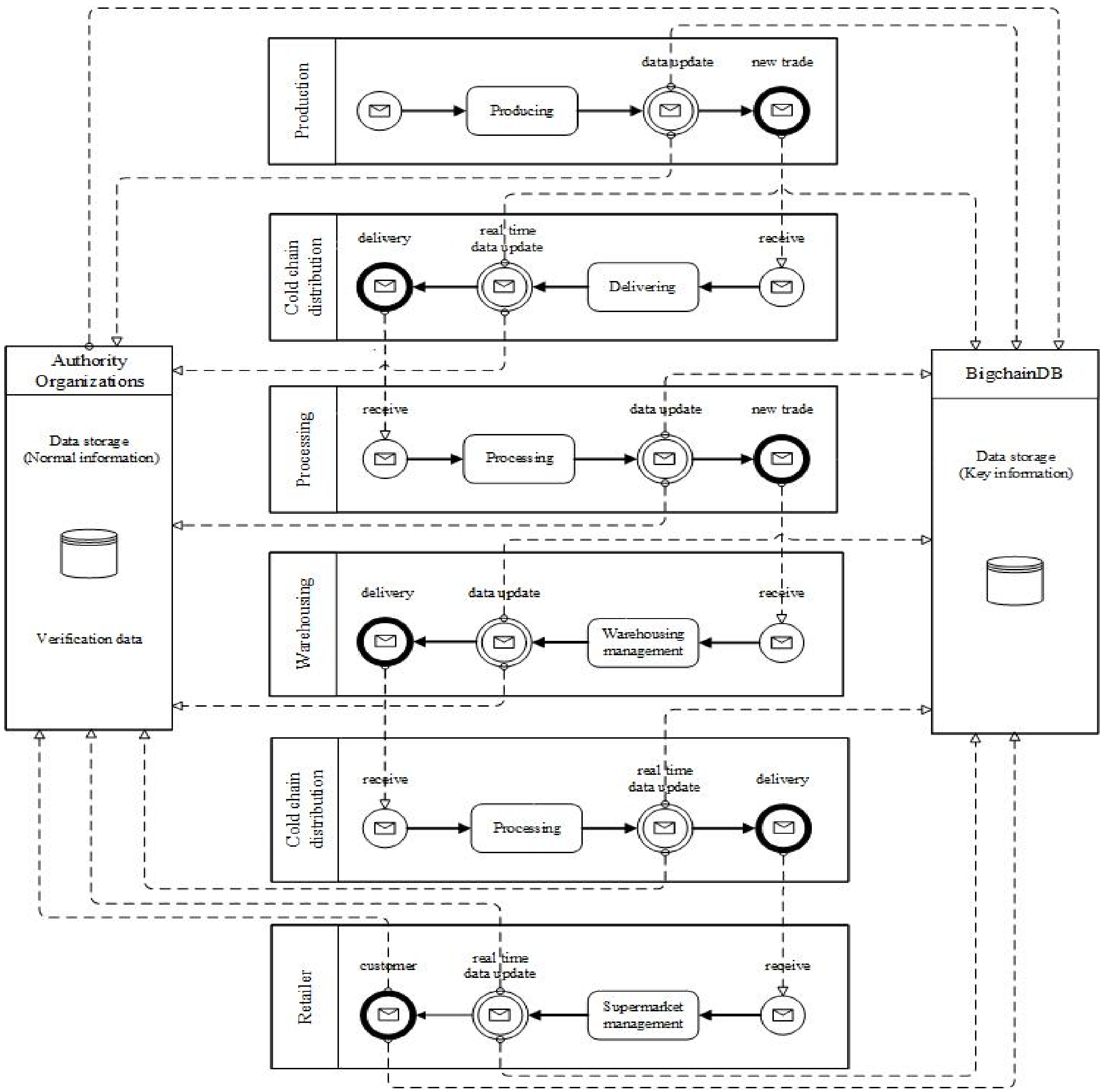

Fig. 5. Information flow diagram for the food supply chain participants within our traceability system

4.3.5 Keep participants from tampering with the sensors

Every sensor in our system has a unique identity, so when it sends the information to the BigchainDB this information can be stored and never be changed on the BigchainDB as an evidence. Moreover, as we mentioned above, there are still some authorities and third-parties in our system, which could verify, inspect the information from the participants, working as a chain-of-custody system. Furthermore, users in the supply chain will check and inspect the information of the product when they receive it from upstream participants, and transfer it to the downstream participants. If they find the data which stored in the product's digital profile can not match the original attributes of the product, they can raise the alarm, and then our system will find where goes wrong and who should be responsible for it immediately.

5. APPLICATION SCENARIO

In this section, an example application scenario is given to show how actions in HACCP can be supported by the proposed traceability system. All food supply chain members mentioned in this scenario, have already registered themselves in the system, and have matched their unique identities and digital profiles in the system.

5.1 Production link

Harvested crop plants are packaged and labeled with RFID Tags, and are entered to the system as new products. Key information of these products can be stored in their profiles. This key information includes: (1) background environment such as quality of soil, water, air, sunlight. (2) plant growing including: quality of the seed, working practices, variety, item number, production area, growth condition, planting time, plucking time, and responsible enterprise even staff etc. (3) information recording and application situation of fertilizers and pesticides. After that, a new trade is initiated between the production enterprise and the processing enterprise, where the products are exchanged after signing a digital contract that stored on the BigchainDB through hand-held tag reader or wireless network.

5.2 Processing link

After receiving products from production enterprises, the processing enterprise reads and enters new data into the product's profile by scanning their tags through their wireless network connected scanners. This information includes: (1) processing environment, such as temperature controlling, disinfecting, and processing equipment. (2) situation of using additives for suitable. (3) basic information of processing enterprise and relevant staff. During the processing, the tags of the raw products may be destroyed, but their digital profiles are updated. After processing operation, new tags can be attached to the packages of finished products.

5.3 Warehousing management link

By setting up relevant Internet of things equipment in warehousing center, the information of received products, such as product's receiving and delivery time can be automatically obtained. Meanwhile, with wireless sensors and monitoring equipment, the real-time storage information of the product, including quantity, category, temperature, humidity, and storage time, can be checked and updated in both product's profile and Tag. Since inventory information can be directly queried in the system or by the RFID reader, this system can also fulfill the enterprise's requirement for dynamic storage management. For example, in order to avoid loss and spoilage, based on the relevant information, managers can make decisions for which products should be given priority to move out of the storage immediately.

5.4 Cold chain distribution link

In the distribution process, the 3T principle (Time, Temperature and Tolerance) is the key factor in ensuring the safety and quality of food products. Therefore, a vehicle-mounted safety monitoring system can be established by setting temperature and humidity sensors in different temperature areas in refrigerator container with vehicle-mounted wireless network and computer. Rely on this monitor system real-time environmental data of products, such as temperature and humidity, can be added to their digital profiles and Tags at regular time intervals. Meanwhile, when the temperature or humidity exceeds the security standard it will raise the alarm immediately. Last but not least, by using GPS, distribution center could implement vehicle positioning for each refrigerated truck and make optimal distribution route to shorten distribution time, which could guarantee the freshness of the food products.

5.5 Retailer link

First of all, when retailers receive the products, they nearly obtain full information of the supply chain that created products. Therefore, consumers can use the RFID reader to obtain the basic information of products when they are shopping. Moreover, thanks to blockchain technology, all the information along the food supply chain is fully audit-able, which means customers could also obtain details information about the final products in a real-time manner by inspecting the traceability system. Secondly, due to the short freshness lifetime of some food product, our system can be applied to monitor the freshness lifetime of products. Therefore, retailers could replace these food products which are close to their expired time. Finally, thanks to our traceability system, once food safety accident happens, the defective products can be located immediately. Furthermore, happening reasons, location and responsible staff can be traced by our system as well, which could extremely reduce the losses and hazards.

5.6 Authority organizations

In different links of food supply chain, authority organizations, such as certifications, audits, third-party authorities, and government departments, will random visit the working field to check whether the rules and regulations are matched, and more important, whether the relevant data has been tampered with before being updated by the participant. After that, inspecting results will be recorded in digital profiles of both parties.

6. CONCLUSION

In this article, we proposed a new decentralized traceability architecture based on internet of things and blockchain technology, and explored the challenges in scaling blockchains in general. Moreover, an example scenario was given to demonstrate how it works in the food supply chain with HACCP. This system will deliver real-time information to all supply chain members on the safety status of food products, extremely reduce the risk of centralized information systems, and bring more secure, distributed, transparent, and collaborative. Our system can significantly improve efficiency and transparency of the food supply chain, which will obviously enhance the food safety and rebuild the consumer’s confidence in the food industry.

However, our system is still in an initial stage. First of all, this system requires advanced IT infrastructure for all members in the supply chain, which maybe too difficult for some participants at the moment. Secondly, this system should prove that it can bring real business benefits, otherwise, supply chain members won’t share the cost for application. Finally, there is a possibility: if there is a super monopoly enterprise which is so powerful that can control the whole supply chain and even the chain-of-custody system, it can enter wrong information and hide the criminal fact, which means the data can be tampered with the sensors. I have to admit that this is the weak link of our system, and we believe that it will be an interesting topic for future researches.

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Paper 4: Evaluation Research on Performance of Chinese Agri-Food Cold-Chain Logistics Company

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Evaluation Research on Performance of Chinese Agri-Food Cold-Chain Logistics Company

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ABSTRACT

Food security concerns are drawing more and more attention in Chinese society. As one of the most effective way for improving food quality and safety, how to promote logistics ability of the cold-chain enterprise has become an emergency issue. This paper aims to build a performance evaluation system for the cold-chain company based on the Chinese agri-food industry to analyze its strengths and weaknesses for improving its competitiveness. Improved Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation methods are blended to evaluate the performance of the target company in three steps. In the first step, rely on the AHP, with the literature review and the theory of the balanced score card method, the determination of evaluation criteria and the hierarchical structure of the evaluation index system are done. In the second step, the weights of each criterion are obtained through improved AHP and then an agri-food cold-chain logistics enterprises performance evaluation index system will be built. And, in the third step, the Fuzzy Comprehensive Evaluation method is used to evaluate the performance of the target company with the performance evaluation index system. Finally, a demonstration of the numerical example in Chinese agri-food industry is presented for better understanding. The proposed performance evaluation index system can assist managers to comprehensive comprehend the strengths and weaknesses of their agri-food cold-chain companies and could continuously improve the relevant cold-chain performance factors from the practice.

Keywords - Agri-food logistics; cold-chain; performance evaluation; improved Analytic Hierarchy Process (AHP); fuzzy comprehensive evaluation

1. INTRODUCTION

With the rapid growing of Chinese economics, the living standard of the people has been constantly improved. Therefore, people pay more attention to the food quality and safety. However, recently a series of food harm scandals, like the case of Sanlu, shows that consumers alike are vulnerable to food quality and safety problem (Ying Kei Tse & Kim Hua Tan, 2011) [1]. Furthermore, it is estimated that about 90% of the total production of fresh meat and 80% of the total production of vegetables and fruits (Sun, 2009) [2] are under the poor logistics which result in huge waste and cost increasing. Since China is a populous country, the security and cost of the agri-food have an essential significance for it. As the most effective method to solute these issues, cold-chain starts playing a more and more important role in our social life.

As a special product, agri-food, including vegetable, fruit, milk, live seafood, meat and meat products, etc. has its inherent characters like freshness, seasonality, regionality and putrescibility. How to keep these characteristics during the logistics process is the key factor for achieving their high margin. However, due to the backward development history of Chinese logistics industry, in general, the cold-chain logistics industry, especially the cold-chain companies which provide professional logistics service is still in the infancy stage. Their infrastructures like refrigerator car, refrigeration storage and information systems, etc. are deficit. Moreover, their specialization levels and service qualities are uneven. In light of above, there are an intense demand and opportunity for the improvement for technology and research advancement within this field.

The rest of the paper is organized as follows: Section 2 presents the relevant literature review. Section 3 is the construction process of the evaluation model which incorporates the fuzzy AHP and the fuzzy comprehensive evaluation methods. Then, an example is presented in section 4 to demonstrate how the model works. Section 5 is the conclusion.

2. LITERATURE REVIEW

Performance measurement system (PMS) is used to evaluate performance and determine future action on a strategic, tactical and operational level (Gunasekaran, patel, & Tirtiroglu, 2001) [3]. Li & Zu (2007) [4] incorporated social responsibility into balance scored card (BSC). And constructed the performance evaluation index system of the logistics company from 5 aspects: finance, customer, internal process, learning & development, and social responsibility. Nevertheless, building the performance evaluation system of a cold-chain is complex, because it has many special characteristics like long production throughput time, large investment, refrigerated transportation and storage requirement, product quality and safety, etc. (Aramyan et al., 2007) [5].

A few studies have been done on the agri-food supply chain. Sun (2009) [2] presented the development strategy of Chinese agri-food cold-chain based on the comparative study of the cold chain industry development status between China and foreign countries. Besides, Chan et al. (2006) [6] insisted that in order to enhance the performance of the whole cold chain there is a need to concern the factors with which the performance of the products, process and services can be evaluated. Agri-food as a special product, their inherent characters were also taken into account during the performance evaluation process. Bogataj et al., (2005) [7] have researched the stability of the agri-food in the cold chain and discussed the factors which decrease the hygiene and quality of the perishables. For perishables, keeping the expectedness safety, quality and freshness always require related equipment with guaranteed thermal characteristics, appropriate information system and proper operating modes (Manning et al., 2006) [8]. Rijswijk & Frewer (2008) [9] stated the important role of IT infrastructure of cold chain and studied that traceability is not only linked to food security, but also to food quality.

AHP and fuzzy comprehensive evaluation are employed in this paper. AHP is utilized in solving multi-criterion decision-making (MCDM) problems. And such kinds of problems could be solved analytically when all the parameters are quantitative (Wang et al., 2011) [10]. However, many evaluation criteria are qualitative in nature. AHP could set up a hierarchy of criteria and sub-criteria, which could be either quantitative or qualitative in nature. And this can be done by building the pair-wise comparison between the criteria, which are evaluated by experts in the relevant area. Unfortunately, AHP is unable to deal with the uncertain and ambiguous variables (Wang et al., 2008) [11]. In order to dress this deficiency, fuzzy AHP which blend AHP with fuzzy comprehensive evaluation has been developed and used in solving many industrial problems. Güngör et al., (2009) [12] utilized fuzzy AHP to rank the performance of different applicants for human resources selection. In this paper, an improved AHP has been used to determine the index weights, which introduced tolerance matrix into fuzzy AHP. It is a fundamental solution to the problems of the matrix consistency test. This method could not only reduce the workload of the repeated re-construct the judgment matrix, but also insure the consistency of the comparison matrix, which could simplify the process of index weights determination (Liu et al., 2012) [13].

According to the literature review above, few researches have been done for constructing the performance evaluation system for agri-food cold-chain enterprise. And there is no performance evaluation system exists in an agri-food cold-chain which has used the improved AHP and fuzzy comprehensive evaluation methods, and integrated both qualitative and quantitative factors into the evaluation system. In this paper, a performance evaluation system is developed for evaluating the performance of agri-food cold-chain enterprises and it could provide some references for the improvement of Chinese cold-chain logistics industry.

3. DESIGN OF THE EVALUATION MODEL

3.1 Framework of the hierarchical structure

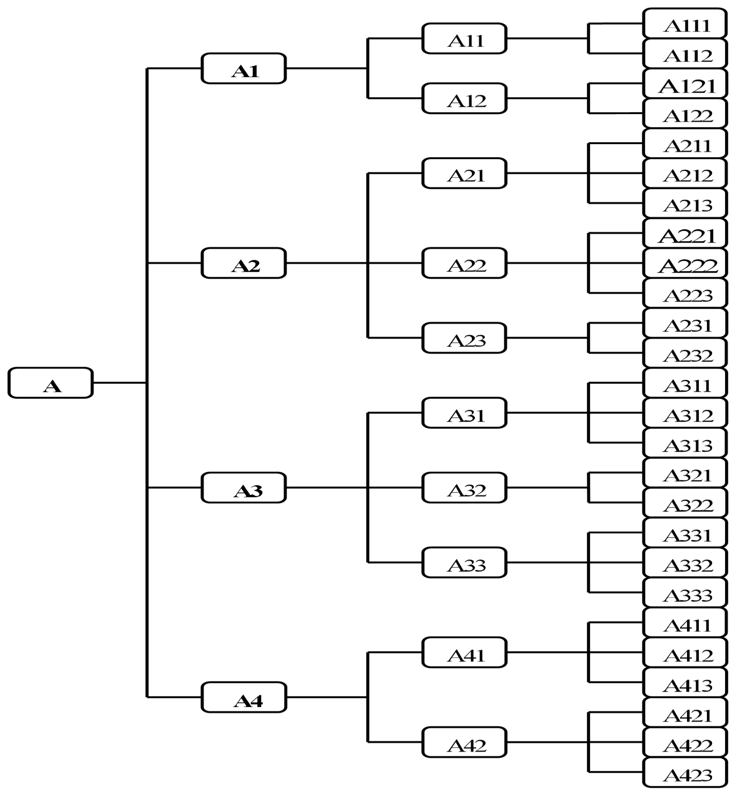

Fig. 1. Hierarchical structure of agri-food cold-chain logistics enterprise performance evaluation index system. A: performance evaluation goal

The agri-food cold-chain logistics enterprise performance evaluation index system was constructed based on the BSC. As illustrated in Fig. 1, the whole evaluation system has 3 levels. The first level including 4 indexes: A1: Finance; A2: Customer & Service; A3: Internal Process; A4: Learning & Development. And there are 10 indexes in the second level: A11: Operation & Management; A12: Survival & Development; A21: Market

Exploration; A22: Service Process; A23: Service Effect; A31: Delivery; A32: Storage; A33: Information; A41: Human Resources; A42: Technical & Innovation. And 26 indexes in the third level (Table 2).

Based on the literature review, this paper selected some indexes which have been rather frequently used. However, since we tried to provide the indexes as complete as possible in the beginning, some of these indexes inevitably overlapped and some were combined. As a consequence, questionnaire survey and statistical analysis method were used to filtrate and modify the indexes. A visit to the academia institutes and relevant cold-chain companies was undertaken and totally 150 questionnaires had been sent to the experts of academia and managers of the companies by email, online interview and on the spot, and about 84 of them were got back in which 80 are available. The response rate is 56% and the effective rate is 53.3%. Furthermore, in these 80 available questionnaires some of them were got back from the experts of the foreign academia such as Australia, USA and Germany, and rest of them are come from Chinese academia institutes and relevant cold-chain companies. Table 1 shows the education background and the working experience of the respondents.

Table 1. Basic information of the respondents

Category	Information	Sample size	Proportion
Education Background	Bachelor degree	18	22.5%
	Master degree	42	52.5%
	PhD degree	20	25.0%
Working Experience	1-3 years	18	22.5%
	3-5 years	38	47.5%
	Above 5 years	24	30.0%

According to the result of the questionnaire survey, concentration degree of experts' opinions is used to filtrate to indexes. In this method, less coefficient of variation value represents the stronger coordination. And if the coefficient of variation value is great than 0.5, the result should be refused (Yang et al., 2007) [14]. As is shown in Table 2, 36 indexes had been identified in this process and the number was reduced to 26.

Table 2. Final performance evaluation indexes

No	Index	Concentration degree	Coefficient of variation
A111	EVA	3.363	0.379
A112	Liquidity Ratio	2.925	0.388
A121	Debt Asset Rate	3.163	0.494
A122	Cold-Chain Profit Growth Rate	3.988	0.335
A211	Market Demand Survey	2.975	0.411
A212	Customer Consulting Service	3.813	0.286
A213	Capacity of Communication With Farmer	3.763	0.352
A221	On Time Delivery Rate	3.675	0.323
A222	Time Consumption of Order-Distribution	2.638	0.406
A223	Cold-Chain Distribution Security Capacity	2.913	0.424
A231	Customer Acquisition Rate	3.225	0.476
A232	Customer Retention Rate	3.700	0.323
A311	Cold-Chain Fully Loaded Rate	3.075	0.479
A312	Cold-Chain Transporting Loss Rate	3.763	0.352
A313	Transporting Fresh-Keeping Capacity	4.013	0.311
A321	Refrigeration Storage Turnover Rate	4.075	0.267
A322	Product Freshness Preservation Capacity	3.638	0.313
A331	Informatization Coverage Rate	2.813	0.404
A332	Information Accuracy Rate	3.875	0.297
A333	Information Monitoring Capacity	3.688	0.319
A411	Staff Satisfaction Level	3.113	0.418
A412	Staff Quality Level	2.613	0.433
A413	Staff Training Level	3.600	0.314
A421	Cold-Chain Research Investment Rate	3.375	0.446
A422	Cold-Chain Equipment Replacement Rate	3.300	0.471
A423	Cold-Chain Return On Research	3.525	0.440

3.2 The definitions of indexes

3.2.1 Finance

A1-Finance: Based on the BSC, finance index can be used to reflect the operation and development status of the company. And it can be divided into two sub-factors, operation & management and survival & development.

A11-Operation & Management is measured by EVA and liquidity ratio of the company.

A111-EVA (Economic Value Added) is the margin between NOPAT (Net Operating Profit After Tax) and invested capital of the company. It is an efficiency index (the value is the higher the better).

A112-Liquidity Ratio: Percentage of current assets/total assets. It reflects the debt paying ability of the company and this is a neutral index (the value is closer to the fitness value the better).

A12-Survival & Development is measured by the debt asset rate and profit growth rate.

A121-Debt Asset Rate: Percentage of total indebtedness/total asserts. It reflects the debt and risk taking capacity of the company. It is a neutral index.

A122-Cold-chain Profit Growth Rate: Percentage of (profits by cold-chain/profits by normal temperature chain). This index reflects the business development status of the company and it is an efficiency index.

3.2.2 Customer & Service

A2-Customer & Service is the basis of exploiting and utilization the enterprise exterior resources. It is constituted by three sub-factors: market exploration, service process and service effect.

A21-Market Exploration reflects the ability of chasing for market share. It can be measured through market demand survey, customer consulting service and capacity of communication with farmers.

A211-Market Demand Survey: in order to exploit more potential customers, cold-chain companies need to make the complete and detailed market research.

A212-Customer Consulting Service: from the purchasing raw agricultural products to clients' dining table, cold-chain could provide all kinds of specialized service in the whole service process. Hence, customers could find satisfied service items by consulting service.

A213-Capacity of Communication with Farmer: as a special product, agri-food has its inherent characters such as freshness, seasonality, regionality, putrescibility and large market demand volatility. Therefore, cold-chain companies need to help farmers master the marketing information and protect their benefit to the maximum extent by communicating with farmers timely.

A22-Service Process: This process will influence the delivery quality directly. It can be measures by on time delivery rate, time consumption of order-distribution and cold-chain distribution security capacity.

A221-On Time Delivery Rate: Percentage of delivery on time times/total delivery times. It is an efficiency index.

A222-Time Consumption of Order-Distribution: Different cargos need different transport distance and requirement. Therefore, different weights should be given to different cargos when consumption time is calculated. It is a cost index (the value is the lower the better).

A223-Cold-Chain Distribution Security Capacity: This index reflects the security level in cold-chain distribution process of the cold-chain company.

A23-Service Effect: By service market exploiting and service process enhancing, its effect could be reflected in the number of clients the company has.

A231-Customer Acquisition Rate: Percentage of increase in customers of current period/the number of customers of the prior period. It is an efficiency index.

A232-Customer Retention Rate: Percentage of the difference between the number of total customers and added customers of current period/the number of customers of the prior period. It reflects the customer retention ability of the cold-chain company, and it is an efficiency index.

3.2.3 Internal Process

A3-Internal Process: Compared to common logistics, cold-chain requires high-tech equipment and large transport cost, and hence enhancing technology contents of equipments and efficient operating various kinds of logistics activities could greatly improve logistics service quality and reduce its cost.

A31-Delivery: During the delivery process of cold-chain, a constant low temperature environment is needed, and delivery capacity will influence the service quality of the cold-chain company directly. In this paper cold-chain fully loaded rate, cold-chain transporting loss rate and fresh-keeping transporting capacity are selected to measure the delivery ability.

A311-Cold-Chain Fully Loaded Rate: Percentage of actual loading of transportation/loading capacity of transportation. This index could reflect the transporting management level of the cold-chain company, and it is an efficiency index.

A312-Cold-Chain Transporting Loss Rate: Percentage of value of the transport losses/value of the total transport goods. This index could indicate the security level of the cold-chain transportation. It is a cost index.

A313-Transporting Fresh-Keeping Capacity: The refrigerated transport equipments the cold-chain company has, and the degree of market demand and agri-food quality could be achieved.

A32-Storage: Like the delivery, storage capacity is another aspect that could influence the service quality. In this paper refrigeration storage turnover rate and product preservation capacity is selected to measure the storage ability.

A321-Refrigeration Storage Turnover Rate: Percentage of the time of agri-food in cold storage/the shelf life of agri-food in cold storage. It is an efficiency index.

A322-Product Freshness Preservation Capacity: The size of cold storage and the technological level of cold storage facilities the cold-chain company has, and the ability of it for ensuring the freshness and quality of the agri-food.

A33-Information: With the rapid changing of market demand, the requirement for market response ability and informationalized level of the cold-chain company has improved constantly. Three indexes have been selected to measure the information ability of the agri-food cold-chain company.

A331-Informatization Coverage Rate: Percentage of businesses handled with enterprise information systems/total businesses. This index reflects the system hardware level and the advanced degree of related software for the agri-food cold-chain company. It is an efficiency index.

A332-Information Accuracy Rate: Percentage of accurate transmission times of information activities/total number of information activities times.

A333-Information Monitoring Capacity: In order to keep the agri-food with high quality in the whole cold-chain logistics activities, strict monitoring should be implemented in each link of the cold chain.

3.2.4 Learning & Development

A4-Learning & Development: Good learning ability and solid development foundation are the precondition for the company to obtain long-term profit. Meanwhile, high quality product and service come from constantly learning and innovating. Only in this way, cold-chain company could reduce the operation cost effectively, occupy more market share and maintain the healthy development of the enterprise.

A41-Human Resources: Human resource is the most important resource of the enterprise. Especially in cold-chain companies which contain professional technical, how to retain and train their high quality staffs, particularly those staffs with professional skill and work experience of cold-chain industry, is one of the key factors impacting the performance of the company.

A411-Staff Satisfaction Level: Percentage of resignation number (with bachelor and master degrees or above) per year/total number of staffs. It is an efficiency index.

A412-Staff Quality Level: Percentage of number of staffs with bachelor and master degree or above/total number of staffs. It is a neutral index.

A413-Staff Training Level: The number of training times per year. It is an efficiency index.

A42-Technology & Innovation: Cold-chain industry is a high-tech industry. Therefore, technical innovation is the source of core competitiveness of the enterprise.

A421-Cold-chain Research Investment Rate: Percentage of research investment in cold-chain technology area per year/total profits of the company per year. It is an efficiency index.

A422-Cold-Chain Equipment Replacement Rate: Percentage of investment in replacement and upgrading of cold-chain equipment in current period/investment in replacement and upgrading of cold-chain equipment in the prior period. It is an efficiency index.

A423-The rate of Return on Cold-Chain Research: Percentage of profits created from cold-chain equipment replacement and upgrading/research expenditure for cold-chain equipment replacement and upgrading.

3.3 Determination of indexes weights

In this paper, an improved AHP has been used to determine the index weights [15], which include several steps and the details of this method will be shown in the appendix:

In this paper, 20 questionnaires were sent to the experts and managers of the previous survey, in which 10 questionnaires were sent to the experts and the other 10 questionnaires were sent to the managers. Finally, we got back 15 questionnaires in which 12 are available. Among these respondents, 7 of them are from academia institutes in which 3 respondents are from USA, Germany and Australia, respectively. And the rest of them are all from China. The other 5 respondents are the managers of Chinese relevant cold-chain companies with at least 5 years working experience and master degree or above education background. The effective rate of this questionnaire survey is 80%, and it also meets the requirement of the AHP for the number of the experts, from 10 to 20. Therefore, according to the results of 12 available questionnaires and the formulas from (1) to (8), indexes weights of all levels could be obtained by calculating the mean value of all 12 questionnaires.

The indexes weights of each level are as follows:

The weights of the first level's indexes:

$$\omega = [0.1367,\ 0.2230, 0.2945, 0.3458]$$

The weights of the second level's indexes:

$$\omega_1 = [0.5964,\ 0.4036]$$

$$\omega_2 = [0.2785, 0.3877, 0.3338]$$

$$\omega_3 = [0.3218, 0.2920, 0.3862]$$

$$\omega_4 = [0.3868,\ 0.6132]$$

The weights of the third level's indexes:

$$\omega_{11} = [0.7500,\ 0.2500]$$

$$\omega_{12} = [0.3786,\ 0.6214]$$

$$\omega_{21} = [0.3120,\ 0.2095, 0.4785]$$

$$\omega_{22} = [0.4162,\ 0.2093, 0.3745]$$

$$\omega_{23} = [0.5502,\ 0.4498]$$

$$\omega_{31} = [0.2123,\ 0.3081,\ 0.4796]$$

$\omega_{32} = [0.4418,\ 0.5582]$

$\omega_{33} = [0.3032,\ 0.4317, 0.2651]$

$\omega_{41} = [0.2720, 0.5638, 0.1642]$

$\omega_{42} = [0.3495,\ 0.3728, 0.2777]$

From the final indexes weights above, we can see that in the first level, the weight of A4 is higher than the other three indexes, which means in our questionnaire survey "learning & development" index is the most important influence factor for the agri-food cold-chain logistics enterprise performance, and it can be seen as main source of the core competence of the cold-chain logistics enterprise. In order to provide efficient, safe and high-quality logistics service for its clients, cold-chain enterprises must keep learning and innovating to consummate their management system and update their hardware facilities: information management systems, refrigerated transportation and storage requirement. In the second and third levels, many of the indexes weights are rather similar. While in some case some are significantly more important than others. For instance, in the second level's indexes, the index weight of A42 which is 0.6132 is much higher than the index A41 which is only 0.3868. It means in experts' mind, technical & innovation index is extremely more important than human resources index for the performance of the cold-chain logistics company. Meanwhile, in the third level's indexes, the index weight of A421, A422 and A423 are quite similar, which means experts believe that the influences of indexes cold-chain research investment rate, cold-chain equipment replacement rate and cold-chain return on research on the agri-food logistics company's performance are quite close.

3.4 Process of the fuzzy comprehensive evaluation

(1) Establish the remark grades of the index. The remark grades for each index are linguistic variables with linguistic values V=[V_1, V_2, V_3, V_4, V_5]=[very high, high, middle, low, very low], and its weight vector is P=[5, 4, 3, 2, 1]. There are five evaluation grades for the final performance evaluation score: 4.2-5=excellent; 3.4-4.2= good; 2.6-3.4=normal; 1.8-2.6=bad; 1-1.8=very bad.

(2) Determine the membership degree of the index. For the qualitative indexes, the fuzzy evaluation method is used to build the membership degrees of indexes in each level. In this method, set the number of experts is Q, and the numbers of experts who score the linguistic variables with very high, high, middle, low and very low are Q_1, Q_2, Q_3, Q_4 and Q_5, respectively. Then, the corresponding membership degrees of the indexes are [Q_1/Q, Q_2/Q, Q_3/Q, Q_4/Q, Q_5/Q].

For the quantitative indexes, there are 3 steps to obtain their membership degrees, and they will be demonstrated in the appendix.

3.5 Comprehensive evaluation

Evaluate for the third level's indexes (Zhang, 2006) [16]. $E_{ij} = \omega_{ij} \cdot R_{ij}$, i=1, 2, 3 4; j=1, 2, 3, where, ω_{ij} is the weights of the third level's indexes which belong to the second level's index Aij; Rij is the fuzzy evaluation matrix of the third level's indexes which belong to the second level's index Aij. Similarly, the second level's indexes and first level's indexes can be evaluated respectively through $E_i = \omega_i \cdot R_i$ and $E = \omega \cdot R$. Finally, the final evaluation score of the target index A could be obtained by formula $F = E \cdot P^T$.

4. AN ILLUSTRATIVE EXAMPLE

The performance evaluation model was implemented in an agri-food cold-chain logistics company, which is an established agri-food cold-chain logistics company in Yangzhou, China. According to its requirement, the name of the company has been replaced the Target Company. With the evaluation model, the performance evaluation score of Target Company could be obtained as follows:

4.1 The process of comprehensive evaluation

For the qualitative indexes, 3 experts of academia institutes in China who are familiar with the situation of the Target Company and 9 managers of the Target Company were invited for the questionnaire survey. Based on the fuzzy comprehensive evaluation method and the information of the Target Company, the membership degrees of the qualitative indexes could be calculated (as is shown in the Table 3).

Table 3. Membership degree of the qualitative indexes

Index	Membership degree	Membership degree of qualitative indexes				
		V_1	V_2	V_3	V_4	V_5
A_{211}	Frequency	3	6	5	1	0
	Membership	0.2000	0.4000	0.3333	0.0667	0.0000
A_{212}	Frequency	1	6	6	2	0
	Membership	0.0667	0.4000	0.4000	0.1333	0.0000
A_{213}	Frequency	1	3	6	5	0

	Membership	0.0667	0.2000	0.4000	0.3333	0.0000
A_{223}	Frequency	2	4	7	2	0
	Membership	0.1333	0.2667	0.4667	0.1333	0.0000
A_{313}	Frequency	1	3	7	3	1
	Membership	0.0667	0.2000	0.4667	0.2000	0.0667
A_{322}	Frequency	1	3	6	4	1
	Membership	0.0667	0.2000	0.4000	0.2667	0.0667
A_{333}	Frequency	0	2	8	3	2
	Membership	0.0000	0.1333	0.5333	0.2000	0.1333

Table 4. Information of the quantitative indexes

Index	Index type	Unit	X_{max}	Value C	X_{min}	Original value
A_{111}	Efficiency	10,000￥	45	—	20	30
A_{112}	Neutral	%	55%	25%	15%	66%
A_{121}	Neutral	%	65%	60%	25%	43%
A_{122}	Efficiency	%	100%	—	0%	23%
A_{221}	Efficiency	%	100%	—	0%	95%
A_{222}	Cost	h	120	—	72	84
A_{231}	Efficiency	%	100%	—	0%	37%
A_{232}	Efficiency	%	100%	—	0%	77%
A_{311}	Efficiency	%	100%	—	0%	88%
A_{312}	Cost	%	50%	—	0%	8%
A_{321}	Efficiency	%	100%	—	0%	21%
A_{331}	Efficiency	%	100%	—	0%	27%
A_{332}	Efficiency	%	100%	—	0%	73%
A_{411}	Efficiency	%	100%	—	0%	80%
A_{412}	Neutral	%	100%	—	0%	57%
A_{413}	Efficiency	times/year	6	4	1	2
A_{421}	Efficiency	%	100%	—	0%	12%
A_{422}	Efficiency	%	100%	—	0%	24%
A_{423}	Efficiency	%	100%	—	0%	38%

Table 5. Membership degree of the quantitative indexes

Index	Standard value	Membership degree of quantitative indexes				
		V_1	V_2	V_3	V_4	V_5
A111	0.4000	0.0012	0.0703	0.4940	0.3978	0.0367
A112	0.4667	0.0043	0.1461	0.5759	0.2620	0.0135
A121	0.8800	0.4845	0.4640	0.0509	0.0006	0.0000
A122	0.2300	0.0000	0.0055	0.1678	0.5894	0.2373
A221	0.9500	0.6437	0.3361	0.0201	0.0001	0.0000
A222	0.7500	0.2003	0.5916	0.2003	0.0078	0.0000
A231	0.3700	0.0007	0.0481	0.4385	0.4579	0.0548
A232	0.7700	0.2373	0.5894	0.1678	0.0055	0.0000
A311	0.8800	0.4845	0.4640	0.0509	0.0006	0.0000
A312	0.8400	0.3893	0.5273	0.0819	0.0015	0.0000
A321	0.2100	0.0000	0.0039	0.1388	0.5797	0.2776
A331	0.2700	0.0000	0.0109	0.2360	0.5862	0.1669
A332	0.7300	0.1669	0.5862	0.2360	0.0109	0.0000
A411	0.8000	0.2988	0.5724	0.1265	0.0032	0.0000
A412	0.5700	0.0238	0.3350	0.5359	0.0996	0.0021
A413	0.3333	0.0003	0.0291	0.3633	0.5251	0.0858
A421	0.1200	0.0000	0.0006	0.0509	0.4640	0.4845
A422	0.2400	0.0000	0.0065	0.1837	0.5914	0.2184
A423	0.3800	0.0011	0.0796	0.2128	0.6366	0.0699

For the quantitative indexes, the membership degrees of each index could be obtained through the formulas (9) to (12). Table 4 and Table 5 present the information of the quantitative indexes and final results, respectively.

Then, based on the membership degrees of qualitative and quantitative indexes above, their corresponding fuzzy evaluation matrix could be constructed. And the calculation details of the comprehensive evaluation will be shown in the appendix.

Finally, the final evaluation score of the target index A is

F=2.9289, according to the five evaluation grades, the final performance evaluation grade of this agri-food cold chain logistics company is normal.

Similarly, the final evaluation score and performance evaluation grade of all target indexes are as follows: F1=2.7555 is normal; F11=2.6684 is normal; F12=2.8844 is normal;

F2=3.5112 is good; F21=3.3127 is normal; F22=4.0319 is good; F23=3.1909 is normal; F3=3.0924 is normal; F31=3.7061 is good; F32=2.5004 is bad; F33=3.0286 is normal; F4=2.4825 is bad; F41=3.3654 is normal; F42=1.9255 is bad.

4.2 Results analysis and management suggestion

The final performance evaluation grade of the target company is normal, which means the overall cold-chain logistics level of this company is normal. The main performances are as follows:

(1) The resource utilization of the target company is low. It can be reflected by the performance evaluation grade of A1-Finance which is only normal. Specifically speaking, its sub-factors A11-Operation & Management and A12-Survival & Development can indicate the allocative efficiency of the enterprise capital, development opportunity and risk resistance ability of the enterprise. Since their evaluation grades are only normal, we can find the resource utilization of the target enterprise is low. However, the performance evaluation grade of A1-Finance is only one result of the overall performance of the enterprise, and it can be affected by the other indexes.

(2) The target company's customer service orientation is strong. The evaluation grade of index A2-Customer & Service is good, which means target enterprise have strong customer service orientation, and it reflect that face the fierce market competition, enterprise normally pay great attention to its service link to reach more customers so that it could take bigger share of market. However, its sub-factors, A21-Market Exploration and A23-Service Effectiveness, their evaluation grades are only normal, it illustrate that first, there still have room for target company to improve its market exploration ability; and secondly, after all, cold-chain logistics is an emerging industry in China. Therefore, like our target company, most of the Chinese companies lacked modern logistics management technology and related service experience.

(3) The cold-chain facilities are weak. As the evaluation grade of the index A3-Internal Process is just normal, it reflects that the cold-chain facilities of the target company are poor and its information-based degree is also low, which are also the factors that constrained the further development of Chinese cold-chain logistics enterprises. In fact, since the equipment demanding is high for the cold-chain industry, there are seldom companies having the ability to provide an entire cold-chain service with high-quality; moreover, refrigeration transportation and transportation storage require huge investments, so for risk reasons, some of the Chinese cold-chain logistics companies would rather rent

the cold-chain facilities, which has severely restricted the development of Chinese cold-chain logistics enterprises.

(4) The professional cold-chain logistics talents are badly deficiency. Among the first level indexes, the performance evaluation score of index A4-Learning & Development is the lowest one, and its evaluation grade is only bad. The lack of high-quality professional talents can be the main reason for this bad result, and it can also result in poor technological innovation capacity for the company. This can be reflected by its sub-factors A41-Human Resources and A42-Technical & Innovation, and their evaluation grades are normal and bad. Obviously, the lack of professional talents and poor innovation capacity will definitely influence the finally performance of the whole cold-chain logistics enterprise.

As an integral system, every index of the enterprise will affect each other, and they will also determine the final performance of the target company together as well.

Based on the analysis above, several management suggestions are given in this paper.

(1) Improve service quality and operational conditions. Target company can further enhance its service quality, instilling customer-oriented service conception, to exploit more markets. Meanwhile, it should avoid the risk as far as possible, and choose the investments very carefully. Moreover, target company could try to build the form of cooperative alliance with the production sides, so that it could provide more professional and personalized service for them.

(2) Strengthen the cold-chain facilities and enhance the information systems construction. In the first place, on the one hand, the lack of the cola-chain facilities is the common problem for the most of Chinese cold-chain logistics enterprise. But one the other hand, having the top-notch cold-chain logistics technical equipment is the key to provide high-class cold-chain service. In this aspect, more supports could be given by government, such as, expansion the financing channel and reducing the tax for the enterprises. Secondly, besides cold-chain facilities, target enterprise should enhance the construction of information systems to improve its market response ability. Last but not least, target enterprise should also optimize business processes, integrate internal resources and enhance the coordination between different departments of the enterprise to strengthen its market competitiveness.

(3) More attention should be attached to human resource management and technical innovation. In order to improve the capacity of “Learning & Development”, target enterprise should value the investing on human resource, such as encouraging innovations, reinforcing staff training, and increasing employee satisfaction, to attract and nurture the

cold-chain management talents. In addition, target enterprise can use the method which combines technical import and self-innovation to keep its sustainable innovation ability. Only in this way, target enterprise could promote its performance efficiently and develop its own core competitive ability.

5. CONCLUSION

This paper constructed a performance evaluation model by improved AHP and fuzzy comprehensive evaluation methods for the agri-food cold-chain logistics company. It provides a practical solution by which agri-food cold-chain companies could easily understand the present strengths and weaknesses of themselves. Therefore, necessary actions can be taken into account to address them. Furthermore, this model can be also used for evaluating and selecting the cold-chain 3PL enterprises by the agri-food suppliers. However, there are some limitations in this study. One of the limitations is that the hierarchical structure model was built based on the literature review. Nevertheless, within the cold-chain industry, different companies face the different market environment and have their own operation status. Therefore, a hierarchical structure model should be specifically developed to reflect the nature of the business. Another limitation is that fuzzy AHP include experts' questionnaire survey which can be viewed as the subjectivity rating process. And different people will hold different opinions concerning the rating of one attribute over another.

The suggestion for future research is increasing the sample size of the questionnaire survey which could provide more data for the study to obtain a better research result. Besides, different evaluation indexes can be chosen for the different companies, as per their own market environment, goals and business strategies.

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APPENDIX

1. The steps of the improved AHP method:

Step 1: establish the pairwise comparison matrix A. Based on the experts grading results, the pairwise comparisons are established using a three-point scale to build the matrix A: $A=(a_{ij})_{n\times n}$ in which $a_{ii}=1$ and

$$a_{ij}=\begin{cases}0 & \text{The } ith \text{ element is less important than the } jth \text{ element}\\ 1 & \text{The } ith \text{ element is the equally important with the } jth \text{ element}\\ 2 & \text{The } ith \text{ element is more important than the } jth \text{ element}\end{cases}$$

Step 2: the sequence index of importance r_i:

$$r_i=\sum_{j=1}^{n}a_{ij}\ ;\quad r_j=\sum_{i=1}^{n}a_{ij} \tag{1}$$

Step 3: construct the judgment matrix $B=(b_{ij})_{n\times n}$:

$$b_{ij}=\begin{cases}\dfrac{r_i-r_j}{r_{\max}-r_{\min}}(k_m-1)+1 & (r_i\ge r_j)\\ \left[\dfrac{r_j-r_i}{r_{\max}-r_{\min}}(k_m-1)+1\right]^{-1} & (r_i<r_j)\end{cases} \tag{2}$$

In which rmax=max$\{r_i\}$; rmin=min$\{r_i\}$; km=rmax/rmin.

Step 4: establish the transfer matrix C of judgment matrix B, matrix $C=(c_{ij})_{n\times n}$, in which

$$c_{ij}=\lg b_{ij}\ (i,j=1,2,\cdots,n) \tag{3}$$

Step 5: construct the optimal transfer matrix D of transfer matrix C, matrix D=$(d_{ij})_{n\times n}$, in which

$$d_{ij} = \frac{1}{n}\sum_{k=1}^{n}(c_{ik} - c_{jk}) \quad (4)$$

Step 6: establish the quasi-optimum consistent matrix H of judgment matrix B, matrix H=$(h_{ij})_{n\times n}$, in which

$$h_{ij} = 10^{d_{ij}} \quad (5)$$

Step 7: the eigenvector of matrix H. First, calculate the product of the elements in each line of the matrix H:

$$M_i = \prod_{j=1}^{n} h_{ij} \quad (6)$$

Calculate the square root of Mi:

$$\overline{W_i} = \sqrt[n]{M_i} \quad (7)$$

Step 8: the normalization for $\overline{W} = (\overline{W}_1, \overline{W}_2, \cdots, \overline{W}_n)^T$:

$$W_i = \overline{W}_i \Big/ \sum_{i=1}^{n} \overline{W}_i \quad (8)$$

The $\overline{W} = (\overline{W}_1, \overline{W}_2, \cdots, \overline{W}_n)^T$ is the desired eigenvector, and its vector components are the weights of relative indexes corresponding to their next higher level's index.

In this paper, we choose the A_{22}-Service Process as an example to demonstrate the calculation process.

Table 6. Marking Table of A_{22}-service process

	A_{221}-On Time Delivery Rate $_1$	A_{222} -Time Consumption of Order-Distribution	A_{223}-Cold-Chain Distribution Security Capacity $_{23}$
A_{221}	1	2	2
A_{222}	0	1	1
A_{223}	0	1	1

Based on table 6, we can obtain judgment matrix B by formula (1) and (2):

$$B = \begin{bmatrix} 3.0 & 1.5 & 1.5 \\ 1.5 & 0.5 & 0.5 \\ 1.5 & 0.5 & 0.5 \end{bmatrix}$$

And then via the formula (3) and (4) we can calculate optimal transfer matrix D:

$$D = \begin{bmatrix} 0.0000 & 0.4184 & 0.4184 \\ -0.4184 & 0.0000 & 0.0000 \\ -0.4184 & 0.0000 & 0.0000 \end{bmatrix}$$

After that we can obtain the quasi-optimum consistent matrix H by formula (5):

$$H = \begin{bmatrix} 1.0000 & 2.6206 & 2.6206 \\ 0.3816 & 1.0000 & 1.0000 \\ 0.3816 & 1.0000 & 1.0000 \end{bmatrix}$$

Finally, we can calculate the indexes weights of A_{221}, A_{222} and A_{223} via formula (6)-(8).

$$\omega_{22} = [0.5672,\ 0.2164,\ 0.2164]^{T}$$

Similarly, we can obtain all the other indexes weights.

2. The steps of determining the membership degree for the quantitative indexes:

Step 1: use the dimensionless method (Li et al., 2009) [17] to obtain the standard values of the quantitative indexes. The formulas are as follows:

For the efficiency index:

$$r = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{9}$$

For the neutral index (the value is closer the fitness value C the better):

$$r = \begin{cases} 1 - \dfrac{C - x}{\max\{C - x_{\min}, x_{\max} - C\}}, & x_{\min} < x < C \\ 1, & x = C \\ 1 - \dfrac{x - C}{\max\{C - x_{\min}, x_{\max} - C\}}, & R < x < x_{\max} \end{cases} \tag{10}$$

For the cost index (the value is the lower the better):

$$r = \frac{x_{\max} - x}{x_{\max} - x_{\min}} \tag{11}$$

Where x is the original value of the quantitative index; r is the standard value of the quantitative index; C is the moderate value for the neutral index.

Step 2: calculate the membership degrees of 5 remark grades for each index. The formulas are as follows (Li et al., 2009) [17]:

$$u_i = \begin{cases} \text{very low:} \ u_1 = e^{-25(r-0)(r-0)\ln 2} \\ \text{low:} \ u_2 = e^{-25(r-1/4)(r-1/4)\ln 2} \\ \text{middle:} \ u_3 = e^{-25(r-2/4)(r-2/4)\ln 2} \\ \text{high:} \ u_4 = e^{-25(r-3/4)(r-3/4)\ln 2} \\ \text{very high:} \ u_5 = e^{-25(r-1)(r-1)\ln 2} \end{cases} \quad (12)$$

The final membership degrees of quantitative index would be obtained by normalized the calculation result.

Step 3: Based on the construct the fuzzy evaluation matrix:

$$R_{ij} = \begin{bmatrix} r_{i111} & r_{i112} & \cdots & r_{i11k} \\ r_{i121} & r_{i122} & \cdots & r_{i12k} \\ \vdots & \vdots & \cdots & \vdots \\ r_{i211} & r_{i212} & \cdots & r_{i21k} \\ \vdots & & \cdots & \vdots \\ r_{ijm1} & r_{ijm2} & \cdots & r_{ijmk} \end{bmatrix} \quad (13)$$

Where i is the serial number of the first level's indexes, i=1,2,3,4; j is the number of the second level's indexes which belong to the first level's index A_i; m is the number of the third level's indexes which belong to the second level's index A_{ij}; k is number of remark grades V_k, k=1, 2, 3, 4, 5; r_{ijmk} is the membership degree of the third level's index which corresponds to the Kth remark grade in remark set V=[V_1, V_2, V_3, V_4, V_5].

3. Calculation details of the comprehensive evaluation:

Comprehensive evaluation for the third level's indexes:

Take the index A11 as an example, $E_{11} = \omega_{11} \cdot R_{11} =$

$$[0.7500, 0.2500] \cdot \begin{bmatrix} 0.0012 & 0.0703 & 0.4940 & 0.3978 & 0.0367 \\ 0.0043 & 0.1461 & 0.5759 & 0.2602 & 0.0135 \end{bmatrix}$$

=[0.0020, 0.0893, 0.5145, 0.3634, 0.0309].

Similarly,

$E_{12} = \omega_{12} \cdot R_{12} = [0.1834,\ 0.1791,\ 0.1235,\ 0.3665,\ 0.1475]$

$E_{21} = \omega_{21} \cdot R_{21} = [0.1083,\ 0.3043,\ 0.3792,\ 0.2082,\ 0.0000]$

$E_{22} = \omega_{22} \cdot R_{21} = [0.3598,\ 0.3636,\ 0.2251,\ 0.0516,\ 0.0000]$

$E_{23} = \omega_{23} \cdot R_{23} = [0.1071,\ 0.2916,\ 0.3167,\ 0.2544,\ 0.0301]$

$E_{31} = \omega_{31} \cdot R_{31} = [0.2548,\ 0.3569,\ 0.2599,\ 0.0964,\ 0.0320]$

$E_{32} = \omega_{32} \cdot R_{32} = [0.0372,\ 0.1134,\ 0.3218,\ 0.3678,\ 0.1598]$

$E_{33} = \omega_{33} \cdot R_{33} = [0.0721,\ 0.2917,\ 0.3148,\ 0.2355,\ 0.0859]$

$E_{41} = \omega_{41} \cdot R_{41} = [0.0947,\ 0.3493,\ 0.3980,\ 0.1427,\ 0.0153]$

$E_{42} = \omega_{42} \cdot R_{42} = [0.0003,\ 0.0247,\ 0.1454,\ 0.5594,\ 0.2702]$

Comprehensive evaluation for the second level's indexes:

$E_1 = \omega_1 \cdot R_1$, where $R_1 = [E_{11}, E_{12}]^T$,

$E_1 = \omega_1 \cdot R_1$ =[0.0752, 0.1255, 0.3567, 0.3647, 0.0780]

Similarly,

$E_2 = \omega_2 \cdot R_2$ =[0.2054, 0.3132, 0.2986, 0.1628, 0.0100]

$E_3 = \omega_3 \cdot R_3$ =[0.1207, 0.2606, 0.2992, 0.2294, 0.0901]

$E_4 = \omega_4 \cdot R_4$ =[0.0368, 0.1503, 0.2431, 0.3982, 0.1716]

Comprehensive evaluation for the first level's index:

$E = \omega \cdot R$, where $R = [E_1, E_2, E_3, E_4]^T$

$E = \omega \cdot R$ =[0.1044, 0.2157, 0.2875, 0.2914, 0.0988]

Then, the final evaluation score of the target index A is:

$F = E \cdot P^T$ =2.9289.

Similarly, we can obtain the evaluation score of all indexes which belong to the first and second levels. The results are as follows: F_1=2.7555; F_{11}=2.6684; F_{12}=2.8844; F_2=3.5112; F_{21}=3.3127; F_{22}=4.0319; F_{23}=3.1909; F_3=3.0924; F_{31}=3.7061; F_{32}=2.5004; F_{33}=3.0286; F_4=2.4825; F_{41}=3.3654; F_{42}=1.9255.

Questionnaire Survey 1: Questionnaire survey for building a agricultural products cold-chain logistics enterprise performance evaluation index system

Dear Mr./Miss,

This questionnaire survey is a very important part of our research which tries to build a performance evaluation index system for the agricultural products cold-chain logistics enterprise. Based on our literature review, 35 evaluation indexes have been selected in this questionnaire survey. As the expert in agriculture logistics and cold-chain areas, your advice is very important to our research. According to the following introductions, please finish this survey in the table.

1. A five-point scale method has been used for indexes significant measurement, which is: 5 points - very important, 4 points - important, 3 points - middle, 2 points - unimportant, 1 point - very unimportant. Please give the scores in the table for each index.

2. According to your knowledge, if you think is necessary to add or cancel certain indexes, please write it down in the opinion column.

3. You can also give your valuable advice in the opinion column.

Questionnaire survey table

Goal	First level	Second level	Third level	Scores
A	Finance A_1	Operation & Management A_{11}	EVA A_{111}	
			Liquidity Ratio A_{112}	
		Survival & Development A_{12}	Debt Asset Rate A_{121}	
			Profit Growth Rate A_{122}	
	Customer Service A_2	Market Exploration A_{21}	Market Demand Survey A_{211}	
			Customer Consulting Service A_{212}	
			Technical Service Capacity A_{213}	
			Communication With Farmer Capacity A_{214}	
			System Flexibility A_{215}	
		Service Process A_{22}	On Time Delivery Rate A_{221}	
			Comprehensive Professional Capacity A_{222}	
			Time Consumption of Order-Distribution A_{223}	
			Delivery Delay Rate A_{224}	

			Customer Complaint Rate A_{225}	
			Cold-Chain Distribution Security Capacity A_{226}	
		Service Effectiveness A_{23}	Customer Acquisition Rate A_{231}	
			Packaging Refund Rate A_{232}	
			Market Shares Growth Rate A_{233}	
			Customer Retention Rate A_{234}	
	Internal Process A_3	Delivery A_{31}	Cold-Chain Fully Loaded Rate A_{311}	
			Transporting Loss Rate A_{312}	
			Transporting Fresh-Keeping Capacity A_{313}	
		Storage A_{32}	Refrigeration Storage Turnover Rate A_{321}	
			Product Preservation Capacity A_{322}	
		Information A_{33}	Informatization Coverage Rate A_{331}	
			Information Accuracy Rate A_{332}	
			Information Monitoring Capacity A_{333}	
	Learning & Development A_4	Human Resources A_{41}	Staff Satisfaction Level A_{411}	
			Labor Costs Level A_{412}	
			Staff Quality Level A_{413}	
			Staff Training Level A_{414}	
			Staff Turnover Ratio A_{415}	
		Technical Innovation A_{42}	Cold-Chain Research Investment Rate A_{421}	
			Cold-Chain Equipment Replacement Rate A_{422}	
			Cold-Chain Return On Research A_{423}	

1.Whether needs add or cancel some certain indexes?________________________________

2. Any other suggestion for us?____

In order to make sure the scientificity of our research, we hope that you could provide following personal information (which will be kept secret strictly).

1. Education Background: Junior College □ Bachelor □ Master and above □

2. Working Experience: 1-2 years □ 3-5 years □ At least 5 years □

Thank you very much for your help!

Questionnaire Survey 2: questionnaire survey for calculating the weights of performance evaluation indexes for the agricultural products cold-chain logistics enterprise

Dear Mr./Miss,

This questionnaire survey is a very important part of our research. Your advice will be the significant evidence for us. Please score the table by pairwise comparison based on your knowledge and experience. Thank you very much for your cooperation!

1. Scoring standard table

Scores	Explain
2	Index A is more important than Index B
1	Index A is equally important to Index B
0	Index A is less important than Index B

2. For example: as is shown in the following table, if A is more important than B then the scores is 2; if A is equally important to C then the scores is 1; if B is less important than C then the scores is 0.

	A	B	C
A	1	2	1
B	--	1	0
C	--	--	1

First Level Indexes

1. Scoring table A of agricultural products cold-chain logistics enterprise performance evaluation

	Finance	Customer Service	Internal Process	Learning & Development
A	A_1	A_2	A_3	A_4
A_1	1			
A_2	--	1		
A_3	--	--	1	
A_4	1--	--	--	1

Second Level Indexes

1. Scoring table A_1 of Finance

	Operation & Management	Survival & Development
A_1	A_{11}	A_{12}
A_{11}	1	
A_{12}	--	1

2. Scoring table A_2 of Customer Service

	Market Exploration	Service Process	Service Effectiveness
A_2	A_{21}	A_{22}	A_{23}
A_{21}	1		
A_{22}	--	1	
A_{23}	--	--	1

3. Scoring table A_3 of Internal Process

	Delivery	Storage	Information
A_3	A_{31}	A_{32}	A_{33}
A_{31}	1		
A_{32}	--	1	
A_{33}	--	--	1

4. Scoring table A_4 of Learning & Development

	Human Resources	Technical Innovation
A_4	A_{41}	A_{42}
A_{41}	1	
A_{42}	--	1

Third Level Indexes

1. Scoring table A_{11} of Operation & Management

	EVA	Liquidity Ratio
A_{11}	A_{111}	A_{112}
A_{111}	1	
A_{112}	--	1

2. Scoring table A_{12} of Survival & Development

	Debt Asset Rate	Profit Growth Rate
A_{12}	A_{121}	A_{122}
A_{121}	1	
A_{122}	--	1

3. Scoring table A_{21} of Market Exploration

	Market Demand Survey	Customer Consulting Service	Communication With Farmer Capacity
A_{21}	A_{211}	A_{212}	A_{213}
A_{211}	1		
A_{212}	--	1	
A_{213}	--	--	1

4. Scoring table A_{22} of Service Process

	On Time Delivery Rate	Time Consumption of Order-Distribution	Cold-Chain Distribution Security Capacity
A_{22}	A_{221}	A_{222}	A_{223}
A_{221}	1		
A_{222}	--	1	
A_{223}	--	--	1

5. Scoring table A_{23} of Service Effectiveness

	Customer Acquisition Rate	Customer Retention Rate
A_{23}	A_{231}	A_{232}
A_{231}	1	
A_{232}	--	1

6. Scoring table A_{31} of Delivery

	Cold-Chain Fully Loaded Rate	Transporting Loss Rate	Transporting Fresh-Keeping Capacity
A_{31}	A_{311}	A_{312}	A_{313}
A_{311}	1		
A_{312}	--	1	
A_{313}	--	--	1

7. Scoring table A_{32} of Storage

	Refrigeration Storage Turnover Rate	Product Preservation Capacity
A_{32}	A_{321}	A_{322}
A_{321}	1	
A_{322}	--	1

8. Scoring table A_{33} of Information

	Informatization Coverage Rate	Information Accuracy Rate	Information Monitoring Capacity
A_{33}	A_{331}	A_{332}	A_{333}
A_{331}	1		
A_{332}	--	1	
A_{333}	--	--	1

9. Scoring table A_{41} of Human Resources

	Staff Satisfaction Level	Staff Quality Level	Staff Training Level
A_{41}	A_{411}	A_{412}	A_{413}
A_{411}	1		
A_{412}	--	1	
A_{413}	--	--	1

10. Scoring table A_{42} of Technical Innovation

	Cold-Chain Research Investment Rate	Cold-Chain Equipment Replacement Rate	Cold-Chain Return On Research
A_{42}	A_{421}	A_{422}	A_{423}
A_{421}	1		
A_{422}	--	1	
A_{423}	--	--	1

Thank you very much for your help!

APPENDIX

1. Introduction of our food safety control system

In this chapter, we describe the structure of our food safety control system and demonstrate how it works. In addition, an example application scenario is given to show how actions in HACCP can be supported by the proposed traceability system in paper 3.

1.1 Logic structure of our research

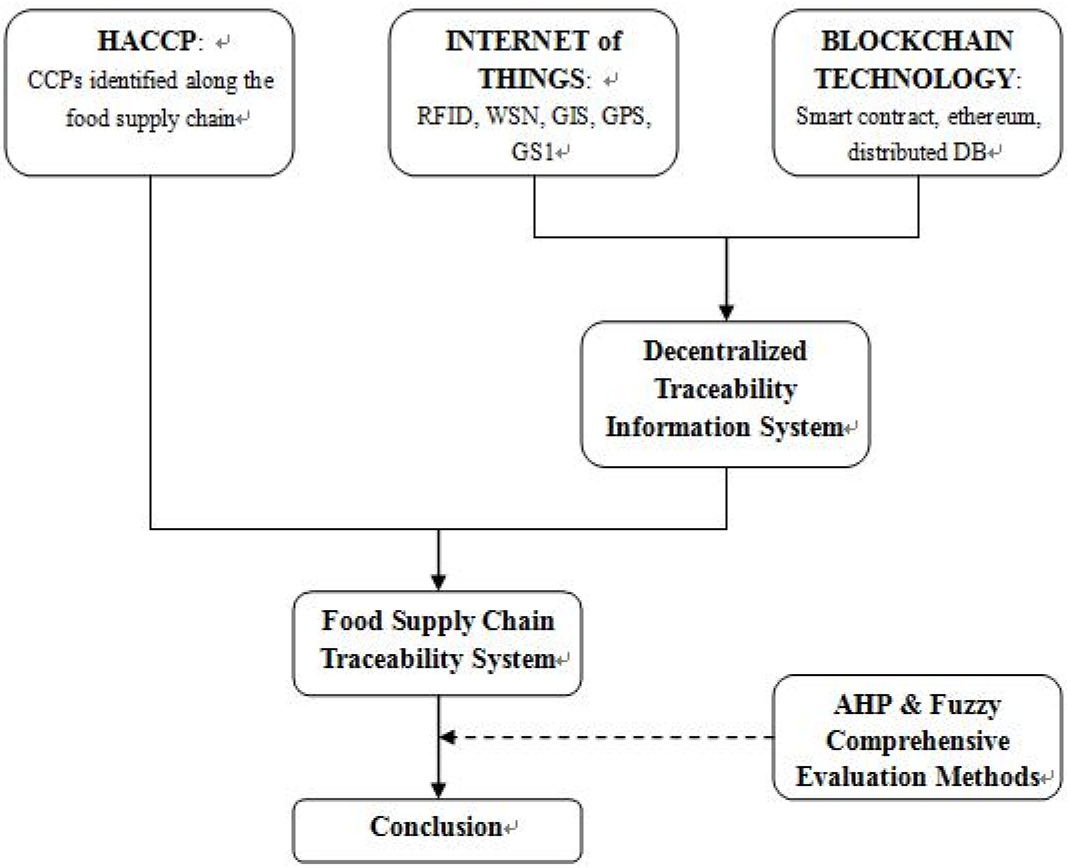

Fig. 5. Basic logical structure of the whole research

Since our research consists of 4 papers, Fig. 5 shows the basic logical structure of our research which connects these papers together. First of all, associated with HACCP, critical control points (CCPs) for the food safety along the food supply chain can be identified, and relevant actions and processes can be further supported by IT systems. Secondly, we introduced the Internet of Things, and details of blockchain technology. Then based on these two technologies we build a decentralized traceability information system. Third, we integrated HACCP with this new traceability system to design a food supply chain traceability system, and demonstrated how it works. Finally, in order to evaluate the improvement in food safety and performance of supply chain management through our system, we proposed a performance evaluation model based on improved AHP and fuzzy comprehensive evaluation methods and demonstrated an illustrative example of an agri-food cold-chain logistics company. We believe that, with this method, empirical studies and tests can be implemented in depth when our artifact can be widely applied in the real business environment in the future. Besides, questions and limitations of our research for future studies were discussed in the conclusion.

1.2 Food supply chain model with HACCP

As is shown in Fig. 13, a typical scenario for the food supply chain is presented and the whole food supply chain is divided into 5 links: A-Production; B-Processing; C-Warehousing; D-Distribution; E-Retail. Associated with HACCP, critical control points for the food safety among the different links can be identified, and relevant actions and processes can be further supported by our traceability information system (the details of an example has been given in paper 3)

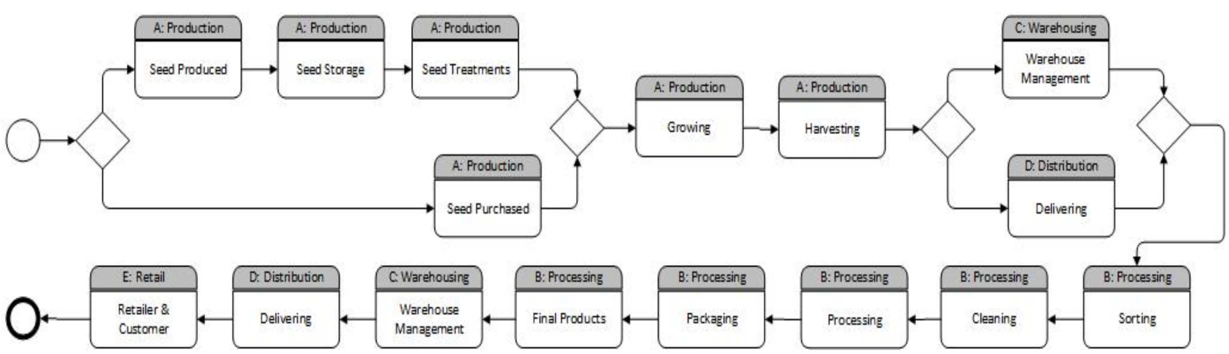

Fig. 13. Flow diagram for the food supply chain

1.3 Structure and main functions of our traceability system

1.3.1 Overview of the traceability system

As one of the most important technology from blockchain, ethereum was used by Bitcoin. It can be seen as a programmable blockchain network, which supports a Turing-complete programming language to write smart contract in. Far beyond the original blockchain, which can be only used to execute transactions for crediting virtual currency/crypto-currency (Bitcoin), in ethereum, variety of smart contacts created by user can be executed by implementing a certain programmable blockchain [60]. Therefore, it has been used in some areas: financial transactions, crowd funding, company management, contract management, and intellectual property.

As shown in Fig. 14, the proposed system is a typical decentralized distributed system, which uses the Internet of things (like RFID, WSN, GPS) to collect and transfer, relies on ethereum to store and manage relevant data of products in food supply chains. There are many members among the supply chain, including suppliers, producers, manufacturers, distributors, retailers, consumers and certifiers. Each of these members can add, update and check the information about the product on the BigchainDB as long as they register as a user in the system. Each product is attached with a tag (RFID), which is a unique digital cryptographic identifier that connects the physical items to their virtual identity in the system. This virtual identity can be seen as the product information profile. Users in the system also have their digital profile, which contains the information about their introduction, location, certifications, and association with products.

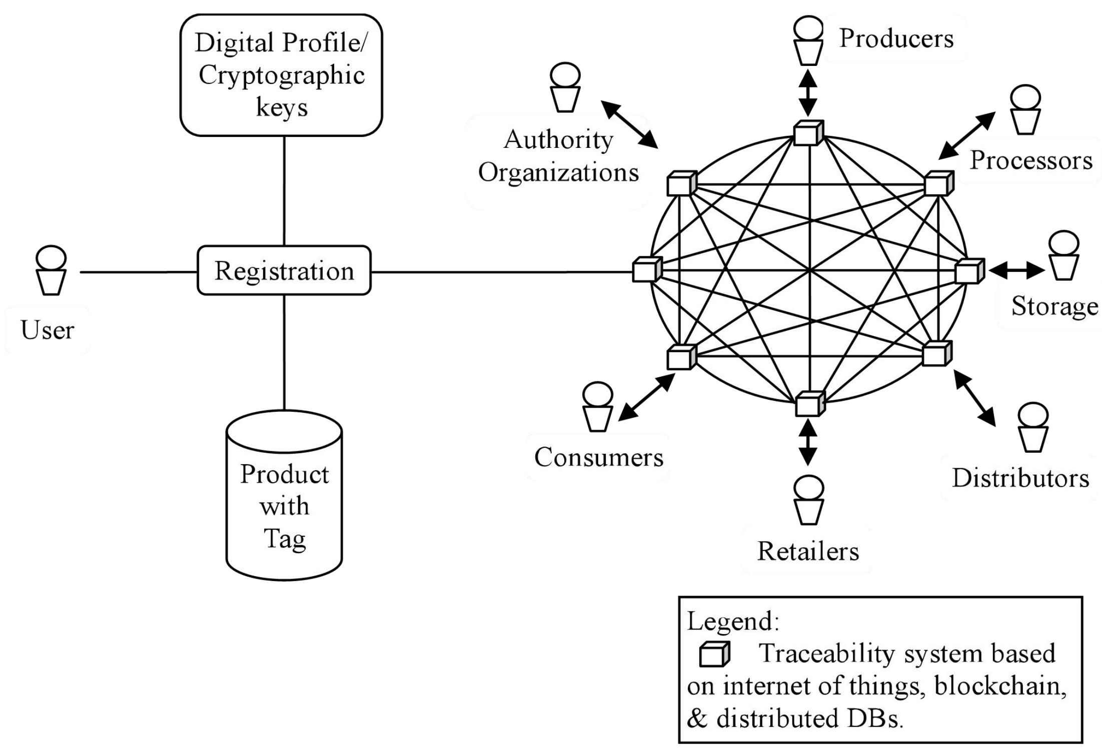

Fig. 14. Conceptual framework of the proposed traceability information system

All data in the system is stored in the BigchainDB and is opened to any user. The system is governed by a set of rules which are written in code and stored in the BigchainDB also. These rules define how users are to interact with the system, and how the data is shared among the users. Moreover, once the rules are stored in the BigchainDB, they can not be altered without broadcasting to all nodes and verified by most of them.

1.3.2 Registration and data updating & adding

Supply chain members can register themselves in the system as a user through the registrar, which can provide credentials and a unique identity to the members. After registration, a public and private cryptographic key pair will be generated for each user. The public key can be used to identify the identity of the user within the system and the private key can be used to authenticate the user when interacting with the system. This enables each product can be digitally addressed by the users when being updated, added, or exchanged to the next user in the downstream position of the supply chain.

In food supply chains, when a user who is in a particular link receives a product, only this user can add new data into the profile of the product with its private key. In addition, when user transfers this product to the next user, both of them have to sign a digital contract to authenticate the exchange. Therefore, the details of the transaction will be added to the BigchainDB and the system will process this data and update the information in the product's profile automatically, which allows users in the system sharing the status of the products at anytime.

1.3.3 Anonymity and sensitive information protection

Our system enables users on the supply chain to transfer and prove the defining attributes and status of their products to any user further along the supply chain. However, some users may want to keep some of their private information secret. Technologically, it is possible for our system to protect identities, while still transferring other important information. For example, producers in the supply chain can pass a digital contract with users from downstream while keeping their identity private. For consumers, maybe they only care about some important status of purchased products without necessarily knowing the full complication information of the whole supply chain that created them.

1.3.4 Role of the authority organizations

In our system there are still some certifications, audits, and third-party authorities, but the difference is that they also have to register and have a digital profile, and, they will take on a new guise implemented in the system. They will check and verify an user's identity and behavior, and records the result in the BigchainDB, available for all to inspect. For instance, certifiers and third-party authorities will visit the factories or facilities to check and inspect whether relevant rules and regulations for standard programs are being met. Once verified by the authorities, the user's profile and its products can be digitally updated and signed by the authority organizations. All the verification data must be published in the system, which extremely enhance the transparency of the supply chain and the safety of the food products.

1.3.5 Keep participants from tampering with the sensors

Every sensor in our system has a unique identity, so when it sends the information to the BigchainDB this information can be stored and never be changed on the BigchainDB as an evidence. Moreover, as we mentioned above, there are still some authorities and third-parties in our system, which could verify, inspect the information from the participants, working as a chain-of-custody system. Furthermore, users in the supply chain will check and inspect the information of the product when they receive it from upstream participants, and transfer it to the downstream participants. If they find the data which stored in the product's digital profile can not match the original attributes of the product, they can raise the alarm, and then our system will find where goes wrong and who should be responsible for it immediately.

1.4 How our system works: overview of the approach

In this part, we will demonstrate an overview of an approach which can be used as a supplementary instruction to explain how our traceability system works.

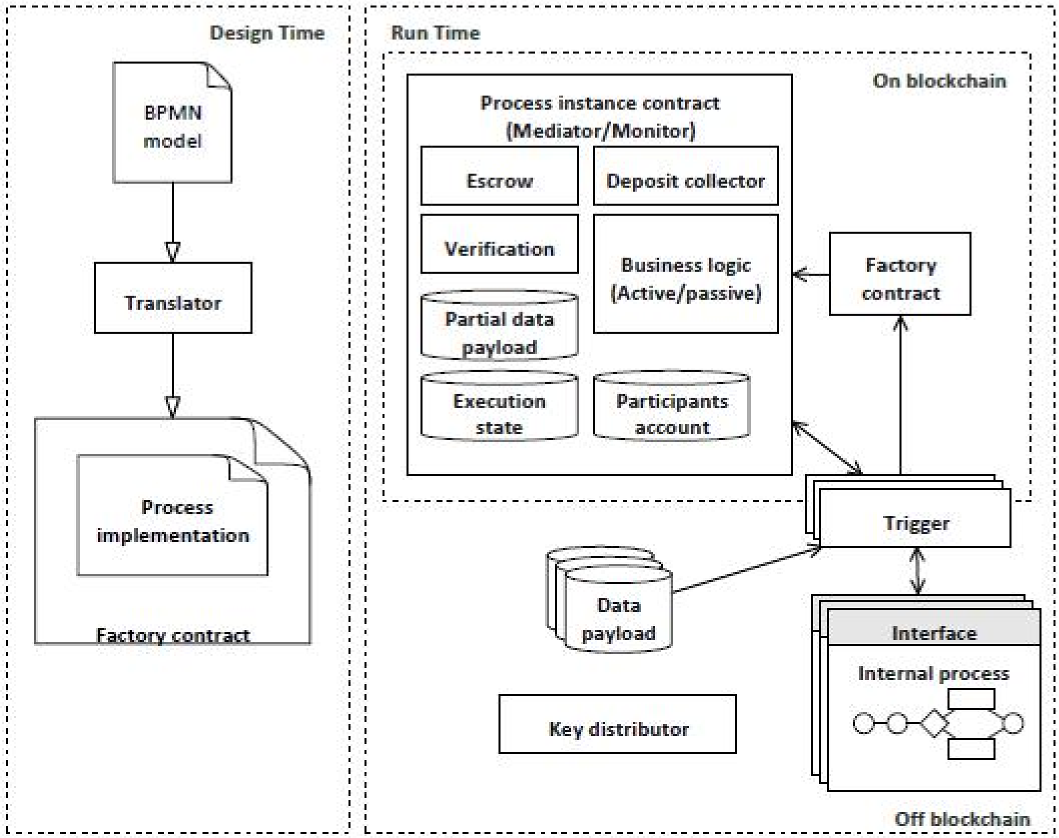

Fig. 15. Overview of the approach (Source: author with reference to Weber et al (2016))[46]

As is shown in Fig. 15, Weber et al. (2016) [46] used blockchain to enable untrusted business process monitoring and execution. They proved that blockchain can be used to facilitate the collaborative process as a monitor or mediator.

As a monitor. Blockchain can be seen as an immutable databases, and all the participants can share and check information in it. In addition, it uses the smart contract to monitor the collaborative processes.

As a mediator. It uses the smart contract to implement the collaborative processes. Different from monitor, mediator plays an active role, receiving and sending information based on the specific logic defined in the process model.

At design time. A translator derives from a process model: Business Process Model and Notation (BPMN), a smart contract in a script language (solidity code). Based on the translation algorithm (translation rules), the translator takes a business process specification (all the elements in the BPMN model) as input and generates smart contracts (solidity code). And these implement the monitor or mediator, and can be run on the blockchain.

Table 5. Translation rule summary. During traversal of the process model, when the translator encounters a pattern (left column), it inserts code according to the right column into the smart contracts code (Source: author with reference to Weber et al. (2016)) [46].

BPMN element	Scope	Solidity code summary
All patterns	All	On execution, deactivates itself and activates the subsequent element.
Parallel-Split	All	Executes on activation, activates *all* subsequent elements.
Parallel-Join	All	Executes on activation of *all* incoming edges.
XOR-Split	All	Executes on activation, conditionally activates all subsequent elements. If one of them is executed, it deactivates all others.
XOR-Join	All	Executes on activation of *one* incoming edge.
Choreography Task	All	Executes when the respective message is received (as blockchain transaction), and if the task is activated (message conforms with process). If conforming, the message is forwarded (as smart contract log entry); else, an alert is broadcasted.
Task: Payment	M,CME	Execution and conformance check as above. If conforming, payment into or from escrow is processed. Incoming payment is through a transaction, which has the desired effect already. Outgoing payment is sent to the account of the specified role.
Task: Data Transformation	M	Execution and conformance check as above. Mediator-internal logic on data transformation, to be handled on-chain by the mediator or off-chain by a designated trigger.

At run time. All the solidity codes generated by translator can be executed on blockchain as smart contract at run time. During the execution, monitor and mediator can be implemented as a smart contract. And all the register users can use smart contract to exchange their data payload. Therefore, process status can be tracked and all transaction can be logged in the blockchain.

Trigger. Since the smart contract can not interact with the external world which is outside the blockchain, the trigger can be seen as an agent which could connect the blockchain and the external world. It can interact with Application Programming Interface in the external world from external devices, and update the process state in the blockchain based on external observations.

In our research, we integrate this approach into our traceability model and Fig. 16 shows the key control measures in the critical control points along the food supply chain. Thanks to Weber and Alexander s' help, we got the positive result and solidity codes.

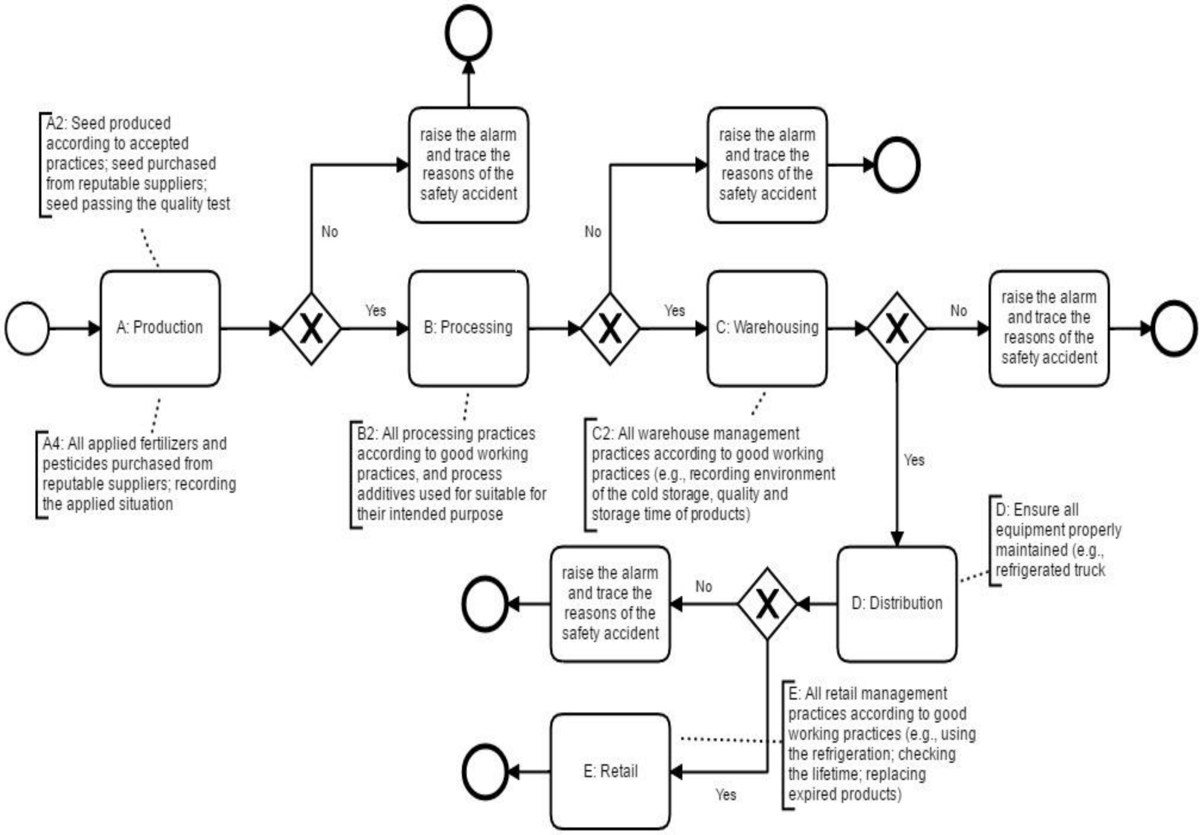

Fig. 16. Flow diagram (BPMN) of the food supply chain with key control measures in the critical control points

2. The solidity code generated from our BPMN model (Fig. 16)

```
/*
pragma solidity ^0.4.8;
*/


/*
ProcessInterface
------------------


D_Distribution,bool safetyInspection
Start
```

```
B_Processing,bool safetyInspection
C_Warehousing,bool safetyInspection
End
raise_the_alarm_and_trace_the_reasons_of_the_safety_accident
E_Retail
A_Production,bool safetyInspection

------------------
Enablements-to-task-map
------------------

        '0x1' : 'A_Production',
        '0x2' : 'raise_the_alarm_and_trace_the_reasons_of_the_safety_accident',
        '0x4' : 'E_Retail',
        '0x8' : 'D_Distribution',
        '0x10' : 'C_Warehousing',
        '0x20' : 'raise_the_alarm_and_trace_the_reasons_of_the_safety_accident',
        '0x40' : 'raise_the_alarm_and_trace_the_reasons_of_the_safety_accident',
        '0x80' : 'B_Processing',
        '0x100' : 'End',
        '0x200' : 'Start',
        '0x400' : 'raise_the_alarm_and_trace_the_reasons_of_the_safety_accident',


*/

/* Only interface */
contract ProcessRegistry {
    function register(address processFactory, string processName, string processType);
```

```
    function getAll() returns (address[]);
    function getNameByAddress(address processFactoryAddress) returns (string);
    function getTypeByAddress(address processFactoryAddress) returns (string);
}


contract ProcessMonitor {
    //uint preconditions = 0x400;

        function getPreconditions(uint instanceID) internal returns(uint);
    function setPreconditions(uint instanceID, uint preconditions) internal;
    event taskCompleted(uint indexed instanceID, string taskName);




    function ProcessMonitor() {
    }

    function D_Distribution(uint256 instanceID, bool safetyInspection) returns (bool) {
        uint preconditions = getPreconditions(instanceID);

        uint predicates = 0;
        if ( (preconditions & (0x28 | 0x800) == (0x28)) ) {
            // ----------------------

            // ----------------------
            // ----------------------
            if ((!safetyInspection)) predicates |= 0x800;
```

```
            // ----------------------
            step(instanceID, preconditions & uint(~(0x28 | 0x800))    | 0x1 | predicates);
                    taskCompleted(instanceID, "D_Distribution");
            return true;
        }
        return false;
    }



    function Start(uint256 instanceID) returns (bool) {
       uint preconditions = getPreconditions(instanceID);

        if ( (preconditions & 0x400 == 0x400) ) {
            step(instanceID, preconditions & uint(~0x400)    | 0x100);
                    taskCompleted(instanceID, "Start");
            return true;
        }
        return false;
    }



    function B_Processing(uint256 instanceID, bool safetyInspection) returns (bool) {
       uint preconditions = getPreconditions(instanceID);

        uint predicates = 0;
        if ( (preconditions & (0x50 | 0x800) == (0x50)) ) {
            // ----------------------

            // ----------------------
```

```
            // ----------------------
            if ((!safetyInspection)) predicates |= 0x800;
            // ----------------------
            step(instanceID, preconditions & uint(~(0x50 | 0x800))    | 0x80 | predicates);
                    taskCompleted(instanceID, "B_Processing");
            return true;
        }
        return false;
    }


    function C_Warehousing(uint256 instanceID, bool safetyInspection) returns (bool) {
      uint preconditions = getPreconditions(instanceID);

        uint predicates = 0;
        if ( (preconditions & (0x84 | 0x800) == (0x84)) ) {
            // ----------------------

            // ----------------------
            // ----------------------
            if ((!safetyInspection)) predicates |= 0x800;
            // ----------------------
            step(instanceID, preconditions & uint(~(0x84 | 0x800))    | 0x20 | predicates);
                    taskCompleted(instanceID, "C_Warehousing");
            return true;
        }
        return false;
    }
```

```
function End(uint256 instanceID) returns (bool) {
    uint preconditions = getPreconditions(instanceID);

    if ( (preconditions & 0x2 == 0x2) ) {
        step(instanceID, preconditions & uint(~0x2) );
                taskCompleted(instanceID, "End");
        return true;
    }
    return false;
}


function raise_the_alarm_and_trace_the_reasons_of_the_safety_accident(uint256 instanceID)
returns (bool) {
    uint preconditions = getPreconditions(instanceID);

    if ( (preconditions & (0x20 | 0x800) == (0x20 | 0x800)) ) {
        step(instanceID, preconditions & uint(~0x20)   | 0x4);
                taskCompleted(instanceID,
"raise_the_alarm_and_trace_the_reasons_of_the_safety_accident");
        return true;
    }
    if ( (preconditions & (0x80 | 0x800) == (0x80 | 0x800)) ) {
        step(instanceID, preconditions & uint(~0x80)   | 0x40);
                taskCompleted(instanceID,
"raise_the_alarm_and_trace_the_reasons_of_the_safety_accident");
        return true;
    }
    if ( (preconditions & (0x1 | 0x800) == (0x1 | 0x800)) ) {
        step(instanceID, preconditions & uint(~0x1)   | 0x8);
```

```
                    taskCompleted(instanceID,
"raise_the_alarm_and_trace_the_reasons_of_the_safety_accident");
            return true;
        }
        if ( (preconditions & (0x10 | 0x800) == (0x10 | 0x800)) ) {
            step(instanceID, preconditions & uint(~0x10)    | 0x200);
                    taskCompleted(instanceID,
"raise_the_alarm_and_trace_the_reasons_of_the_safety_accident");
            return true;
        }
        return false;
    }


    function E_Retail(uint256 instanceID) returns (bool) {
      uint preconditions = getPreconditions(instanceID);

        if ( (preconditions & (0x1 | 0x800) == (0x1)) ) {
            step(instanceID, preconditions & uint(~0x1)    | 0x2);
                    taskCompleted(instanceID, "E_Retail");
            return true;
        }
        return false;
    }


    function A_Production(uint256 instanceID, bool safetyInspection) returns (bool) {
      uint preconditions = getPreconditions(instanceID);

        uint predicates = 0;
```

```
        if ( (preconditions & 0x300 == 0x300) ) {
            // ----------------------


            // ----------------------
            // ----------------------
            if ((!safetyInspection)) predicates |= 0x800;
            // ----------------------
            step(instanceID, preconditions & uint(~(0x300 | 0x800))    | 0x10 | predicates);
                    taskCompleted(instanceID, "A_Production");
            return true;
        }
        return false;
    }



    function step(uint instanceID, uint preconditionsp) internal {
       //uint preconditions = getPreconditions(instanceID);
        if (preconditionsp & 0x7ff == 0) { setPreconditions(instanceID, 0); return; }
        setPreconditions(instanceID, preconditionsp);
    }

    function isProcessInstanceCompleted(uint instanceID) constant returns (bool) {
       return getEnablement(instanceID) == 0;
    }

       function bitSetter_nopredicates(uint value, uint ormask, uint mask) internal returns(uint) {
        if (value & mask == mask) {
            return ormask;
        }
```

```
        return 0;
    }
    function bitSetter_onlyppredicates(uint value, uint ormask, uint mask1, uint ppred) internal returns(uint) {
        if ((value & mask1 == mask1) && (value & ppred == ppred)) {
            return ormask;
        }
        return 0;
    }
    function bitSetter_onlynpredicates(uint value, uint ormask, uint mask, uint npred) internal returns(uint) {
        if ((value & mask == mask) && (value & npred == 0)) {
            return ormask;
        }
        return 0;
    }
    function bitSetter_bothpredicates(uint value, uint ormask, uint mask1, uint ppred, uint npred) internal returns(uint) {
        if ((value & mask1 == mask1) && (value & ppred == ppred) && (value & npred == 0)) {
            return ormask;
        }
        return 0;
    }

    function getEnablement(uint instanceID) constant returns (uint) {
       uint preconditions = getPreconditions(instanceID);
        uint enabledTasks = 0;

        // A_Production

        //if ( (preconditions & 0x300 == 0x300) )
```

```
//      enabledTasks |= 0x1;
                // no predicates here
enabledTasks |= bitSetter_nopredicates(preconditions, 0x1, 0x300 );

// raise_the_alarm_and_trace_the_reasons_of_the_safety_accident

//if ( (preconditions & 0x20 == 0x20) && (preconditions & 0x800 == 0x800) )
//      enabledTasks |= 0x2;
                              // only ppredicates
enabledTasks |= bitSetter_onlyppredicates(preconditions, 0x2, 0x20, 0x800 );

// E_Retail

//if ( (preconditions & 0x1 == 0x1) && (preconditions & 0x800 == 0) )
//      enabledTasks |= 0x4;
                              // only npredicates
enabledTasks |= bitSetter_onlynpredicates(preconditions, 0x4, 0x1, 0x800 );

// D_Distribution

//if ( (preconditions & 0x28 == 0x28) && (preconditions & 0x800 == 0) )
//      enabledTasks |= 0x8;
                              // only npredicates
enabledTasks |= bitSetter_onlynpredicates(preconditions, 0x8, 0x28, 0x800 );

// C_Warehousing

//if ( (preconditions & 0x84 == 0x84) && (preconditions & 0x800 == 0) )
//      enabledTasks |= 0x10;
```

```
                        // only npredicates
enabledTasks |= bitSetter_onlynpredicates(preconditions, 0x10, 0x84, 0x800 );

// raise_the_alarm_and_trace_the_reasons_of_the_safety_accident

//if ( (preconditions & 0x80 == 0x80) && (preconditions & 0x800 == 0x800) )
//      enabledTasks |= 0x20;
                        // only ppredicates
enabledTasks |= bitSetter_onlyppredicates(preconditions, 0x20, 0x80, 0x800 );

// raise_the_alarm_and_trace_the_reasons_of_the_safety_accident

//if ( (preconditions & 0x1 == 0x1) && (preconditions & 0x800 == 0x800) )
//      enabledTasks |= 0x40;
                        // only ppredicates
enabledTasks |= bitSetter_onlyppredicates(preconditions, 0x40, 0x1, 0x800 );

// B_Processing

//if ( (preconditions & 0x50 == 0x50) && (preconditions & 0x800 == 0) )
//      enabledTasks |= 0x80;
                        // only npredicates
enabledTasks |= bitSetter_onlynpredicates(preconditions, 0x80, 0x50, 0x800 );

// End

//if ( (preconditions & 0x2 == 0x2) )
//      enabledTasks |= 0x100;
            // no predicates here
```

```
        enabledTasks |= bitSetter_nopredicates(preconditions, 0x100, 0x2 );

        // Start

        //if ( (preconditions & 0x400 == 0x400) )
        //      enabledTasks |= 0x200;
                // no predicates here
        enabledTasks |= bitSetter_nopredicates(preconditions, 0x200, 0x400 );

        // raise_the_alarm_and_trace_the_reasons_of_the_safety_accident

        //if ( (preconditions & 0x10 == 0x10) && (preconditions & 0x800 == 0x800) )
        //      enabledTasks |= 0x400;
                                // only ppredicates
        enabledTasks |= bitSetter_onlyppredicates(preconditions, 0x400, 0x10, 0x800 );



        return enabledTasks;
    }
    /*
// Library functions
    function uint2string(uint val) internal returns(string) {
        string memory result = new string(256);
        bytes memory result_bytes = bytes(result);
        uint i;
        for (i = 0; i < result_bytes.length; i++) {
            byte rem = (byte)((val % 10)+48);
            val = val / 10;
            result_bytes[i] = rem;
```

```
            if(val==0) {
                break;
            }
        }
        uint len = i;
        string memory out = new string(len+1);
        bytes memory out_bytes = bytes(out);
        for (i = 0; i <= len; i++) {
            out_bytes[i] = result_bytes[len-i];
        }
        return string(out_bytes);
    }
    function strConcat(string a, string b) internal returns(string) {
        return strConcat(a, b, "");
    }
    function strConcat(string a, string b, string c) internal returns(string) {
        bytes memory a_bytes = bytes(a);
        bytes memory b_bytes = bytes(b);
        bytes memory c_bytes = bytes(c);
        string memory result = new string(a_bytes.length + b_bytes.length + c_bytes.length);
        bytes memory result_bytes = bytes(result);
        uint i;
        uint pos = 0;
        for (i = 0; i < a_bytes.length; i++) result_bytes[pos++] = a_bytes[i];
        for (i = 0; i < b_bytes.length; i++) result_bytes[pos++] = b_bytes[i];
        for (i = 0; i < c_bytes.length; i++) result_bytes[pos++] = c_bytes[i];
        return string(result_bytes);
    }
*/
```

```
// -------
}

contract ProcessFactory is ProcessMonitor{
    event instanceCreated(uint indexed instanceID);

    address registryAddress = 0xfc784f5d1b8fbd59f61de652a411d22b4822b676;

    uint[] instancesPreconditions;

    function ProcessFactory(string processFactoryName) {
        ProcessRegistry registry = ProcessRegistry(registryAddress);
        registry.register(this, processFactoryName, "C-MONITOR");

        //in order to start instanceIDs from '1'
        instancesPreconditions.push(987654321);
    }

    //Expects the following roles addresses:
    //TODO:
    //Customer, AccountManager, Mediator, Support1stLevel, Support2ndLevel, SoftwareDeveloper
    function createInstance(address[] _participants) returns (uint) {
        if (_participants.length!=0) {
            throw;
        }

        uint createdInstanceID = instancesPreconditions.length;

        instancesPreconditions.push(0x400); //initial
```

```
        //Fire the createInstance event
        instanceCreated(createdInstanceID);

        //Execute Start() process
            Start(createdInstanceID);

        return createdInstanceID;
    }

    function getPreconditions(uint instanceID) internal returns(uint) {
        return instancesPreconditions[instanceID];
    }
    function setPreconditions(uint instanceID, uint preconditions) internal {
        instancesPreconditions[instanceID] = preconditions;
    }

   //Just an example of how to retrieve the number of created instances
    function getInstancesCount() returns (uint) {
        return instancesPreconditions.length;
    }
}
```

3. The simulation based on the solidity code

The simulation screencast video is available: http://youtu.be/apPmZFzgSDw. And in this section we focus on procedure of the implementation of a supply chain provenance smart contract on a self developed block chain test network. The software used is based on open source software and is supported by the Ethereum Project. This simulation is simplied based on the solidity codes we obtained from our BPMN model, in order to show how the tracking on the Blockchain can be done.

3.1 The solidity code

In this chapter the solidity code for the smart contract is explained. In the following the raw code is displayed:

```
pragma solidity ^0.4.8;

contract PathsDB {

    address[] public path;
    address public owner;

    function PathsDB() {
      owner = msg.sender;
    }

    function addCheckpoint(address checkpoint) returns (bool) {
      if (checkpoint == 0x0) {
        return false;
      }
      if (path.length == 0 || path[path.length-1] != checkpoint) {
        path.push(checkpoint);
        return true;
      }
      return false;
    }

    function getPath() constant returns (address[]) {
      uint length = path.length;

      address[] memory checkpoints = new address[](length);

      for (uint i = 0; i < path.length; i++) {
        checkpoints[i] = path[i];
      }

      return checkpoints;
    }

    function getPathLength() constant returns (uint) {
      return path.length;
    }

    function destroy() {
        if (owner == msg.sender) selfdestruct(owner);
    }
}
```

The contract is called PathDB, which indicated a database for certain supply chain tracking purposes. Both address variables indicate that the contract is available for the public. This means everybody connected to the network can use and alter it. The first function that the smart contract executes is called PathDB. The resulting goal is to assign an owner to the contract. This is done due to transparency reasons. The next function, add Checkpoint, adds the checkpoints in the form of accounts. It gives the account a certain identity starting at 0, this means whichever account is the first checkpoint on the path, the output will be assigned to a value of 0. These are set functions. The purpose of these functions is to alter information on the Blockchain. In order to change or to add information to the Blockchain, transactions have to be mined to achieve consensus. In the further code a get function named get Path Length is used. The result is the length of the supply chain to assure transparency. In order to check where the last valid checkpoint was, the smart contract also allows to query the information. With a simple function a tool for exact tracking was implemented. Since the checkpoints are assigned to numbers and the path length is known, the smart contract allows to query the positions due to the path length. This assures more visibility on the supply chain. In the end the contract can be destroyed after the operations have been completed. The contract will still be found on the Blockchain, but no interaction is possible.

3.2 Using the contract

For the purpose of simplicity a Mist-wallet was used in order to have a better user interface for the blockchain. To simulate a supply chain based on a simple model the following parties were chosen based on a BPMN:

1. Production
2. Processing
3. Warehousing
4. Distribution
5. Retail

These players were projected as accounts on the Blockchain. Every account had to be renamed into the parties description. In terms of controlling the access to the contract a Controller account was created. The Controller deployed the smart contract on the Blockchain. This can only be done by transaction verification through mining using the proof of work algorithm. In the process the controller interacts with the smart contract adding 5 checkpoints. After the supply chain has been implemented into the contract the whole path is visible and each position can be traced using the get function tool explained above.

4. Limitations, questions and discussion

4.1 How can we evaluate our approach practically (which interfaces would be used)? And how practical in situ evaluation of our system (i.e. running experiments with RFID) could be evaluated in a future work summary?

The implementation of the scenario on the blockchain shows mainly the technical components that are needed to set up this kind of system. In addition to this, the smart contract execution shows that supply chain provenance is possible using a simple approach. Extending the scenario is vital for the success of the tracing and tracking process on the blockchain. This model is recording the checkpoints of a unit send over the network by using if else functions in a smart contract on Ethereum. Basically speaking, the quality control part is missing in this scenario. Diving into sub-processes would resolve in a conglomerate of smart contracts that are linked to each other. This provides a basis for the checkpoints in the prototype. For interacting with external internet of things interfaces the smart contract can be accessed by using a localhost internet protocol. The generation of the smart contract comes with the luxury of having a web3 based approach. This assures easy implementation using html and connecting certain UIs with the blockchain. Depending on the type of blockchain this scenario can be accessed by anybody knowing the smart contract address. Since this prototype was executed on a test network, anybody having an account on the ledger can temper the attributes of the smart contract. Meaning that the tracking can change on the participants that are along the supply chain. The system comes with scaled flexibility, meaning that the contract can hold infinite participants. The Limitations of the thesis are clearly unknown attributes of the blockchain and the cryptocurrency systems itself. Identifying major issues along the supply chain requires a more secure approach in which the blockchain is not only the right tool but also a limited one.

In Terms of internet of things interfaces the blockchain can work with RFID chips to generate even more automation of the process. A future work summary would include that the process is mapped onto the blockchain linking RFID technology as input to the blockchain. As a matter of fact, these contracts can not be tempered because of their hard characteristics. Technically speaking the smart contract involves the execution of else functions. If one property of the smart contract not satisfied, the contract fails, indicating that there is an issue. The contract can be executed again from the beginning until it is destroyed.

4.2 How do authorities certify themselves in our blockchain-based approach and how does that interfere with anonymity?

Rely on the public and private key pair blockchain can protect the real identity of the user. However, since information of the transactions are totally public, blockchain can not guarantee the privacy perfectly. For example, Barcelo (2014) [61] pointed out that a user's private information can be revealed by linking to its Bitcoin transactions. We agree with Prof. Polleres' opinion that full anonymity in our designed system is not desired, since the user's identity is public after registration (especially for the authorities). How do authorities certify themselves is a kind of "trusted third party" issues, and some researchers choose to take the government as a trusted party anyway. For example, Xu et al. (2016) [62] used government as a validation oracle that injects external state into the blockchain. However, in our research we suppose that all the authorities can not be trusted. Therefore, we need more authorities (government departments, third parties and independent safety inspection parties) in our system to verify food safety information independently, working as a supervisory mechanism among the authorities to prevent cheating things happen.

4.3 Which alternatives to BigchainDB would exist? How do we consider the scalability vs. security in the context of private vs. public?

In our research, we chose the BigchainDB to deal with the blockchain scalability issues. Many researchers have considered to address this problem: instead of to rely on the node to handle the all the copy of ledger, Bruce (2014) [63] proposed a new crypto-currency scheme, in which old recorded transactions can be removed, and a database called "account tree" can be used to hold the balance of all non-empty addresses. Besides that, in order to reduce the size of transactions, "Segregated Witness" suggested using transactions without the signatures [64]. Eyal et al. (2016) [65] gave their idea in the "Bitcoin Next Generation" to decouple blockchain operation into two parts: the key block for leader selection and the micro-block to store the data. Once the leader is selected, it can be entitled to serialize transactions until the next is selected.

Many researchers also proposed their methods to solve the private security vs. public. Since the user's address on the public blockchain is still possible to reveal user's real identity and personal information. Möser (2013) [66] proposed a mixing service to prevent the private information by transferring transactions from multiple input addresses to multiple output address. For example, user A wants to transfer some money to user B. If A transfer the money to B directly, the relationship between A and B might be revealed. Therefore, A can transfer the money to C (a trusted intermediary) first, and then C will transfer the money to B with multiple inputs c1, c2, c3, etc., and multiple outputs d1, d2, d3, b (address B), etc. So it is really harder to reveal the relationship between A and B. However, C can not be trusted in a real business environment normally. It can cheat the money and reveal the A and B's private information also. In order to deal with these issues, Bonneau et al. (2014) [67] proposed a mix-coin concept, in which the intermediary can encrypt the user's requirements (number of money & transfer data) with its private key. Therefore, if the intermediary did not transfer the money, anyone on the network could know that. Furthermore, the concept of coin-join was proposed by Maxwell (2013) [68], which could shuffle output addresses to prevent cheating and protect the private identity by using a central mixing server. Besides that, Miers et al. (2013) [69] proposed the zero-coin, which is based on the ZKP (Zero Knowledge Proof). ZKP is a kind of encryption technology, which can prove a certain data operation without leak the data themselves. Depends on ZKP, miners can validate a transaction without their digital signatures, they need only validate the coins which belong to a list of valid coins instead.

Currently there are three types of blockchain systems: public blockchain, consortium blockchain and private blockchain. And for certain purposes, different blockchain systems can be used to deal with the issues of scalability vs. private security.

The public blockchain: it can be seen as a totally open network, based on a very strong open source approach. Everyone can copy, send, record and validate the transaction on it. In addition, everyone can take part in the consensus process.

The consortium blockchain: only some pre-selected nodes can take part in the consensus process. This kind of blockchain has some permissive conditions for nodes, and it could create a safe environment for business groups.

The private blockchain: the consensus process is controlled by a specific organization, and only the nodes which come from this organization can take part in the consensus process. The permission for the nodes to read, copy, transfer and record the transaction is strictly restricted. Therefore, transfer of vital data can be safely protected.

Table 6. Comparisons among three types of blockchain systems
(Source: Zheng et al. (2017)) [70]

Property	Public blockchain	Consortium blockchain	Private blockchain
Consensus determination	All miners	Selected set of nodes	One organization
Read permission	Public	Could be public or restricted	Could be public or restricted
Immutability	Nearly impossible to tamper	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus process	Permission-less	Permissioned	Permissioned

Depending on different application cases, different blockchain systems can be used for certain purpose. To be honest, how to balance the scalability vs. private security is still a controversial topic in this area, and no consensus has been reached. Therefore, we believe this could be an interesting research topic for future studies.

4.4 How do we consider the problem of energy consumption in current blockchains?

The reason why current blockchains cost huge energy is that it relies on the POW (Proof of Work) consensus algorithm to create the block. In this method, miners depend on how much work is done to get the probability of mining a block. Therefore, this method involves a high energy consumption. However, another consensus algorithm called POS (Proof of Stake) can be the key to this issue. In this method, miners depend on the wealth or age (how many coins they hold) to obtain the block. For example, a miner is only able to create a block based on the fraction of the Bitcoins he owns. This method is efficient with low energy consumption. However, POS also has some safety problems, such as “nothing at the stake attack” and “hoarding problem” [71]. It seems that until now there is not a perfect solution to this problem, but I agree with Prof. Shou-Cheng Zhang’s opinion “Although blockchain seemingly consumes some energy, but we obtain consensus that is a more valuable treasure”. We think this issue maybe also could be an interesting research topic for future studies.

4.5 How to keep participants from entering wrong information (tampering with the sensors)?

To be honest, that is what exactly happened in the Chinese market, and I believe our system can prevent this to some extent. First of all, every sensor in our system has a unique identity, so when it sends the information to the blockchain this information can be saved and never be changed on the blockchain as an evidence. Moreover, as we mentioned above, there are still some authorities and third-parties in our system, which could verify, inspect the information from the participants, working as a chain-of-custody system.

Secondly, there are a lot of supply chain members in our system, and they will check and inspect the information of the product when they receive it. For instance, in different links among the supply chain, every supply chain member will check and inspect the information of the product when they receive it from upstream members, and transfer it to the downstream members. If they find the data which is saved on the blockchain can not match the original attributes of the product, they can raise the alarm, and then our system will find where it goes wrong and who should be responsible for it immediately.

Finally, there is a possibility. If there is a super monopoly enterprise which is so powerful that can control the whole supply chain and even the chain-of-custody system, it can enter wrong information (tampering with the sensors) and hide the criminal facts. I have to admit that this is the weak link of our system, and we believe that it will be an interesting topic for future researches.

4.6 Whether the costs of the system will be lower than the benefits? Who will pay for those costs?

First of all, as a kind of network cryptography technology and database, blockchain will cost users some money, just like we pay for some software or other kinds of databases. However, as a rising technology, with the rapid development of IT, this application cost will be lower and lower. Besides, the costs of our system are mainly from the equipment of internet of things such as RFID and sensors. If we can realize the large-scale application, their cost could be extremely reduced. However, enterprises will not invest in it if there are not enough returns. Actually, for some high-quality and particular products where a marginal increase of some degree to the price would not affect the willingness of the customers to buy, which means customers maybe would rather pay more for these products for safety and reliability.

Secondly, instead of building a brand new system, our system is based on the internet of things which has been maturely applied in different areas. Actually, we just integrate blockchain technology into it, which can be seen as an upgrade process rather than reconstruction. This means it will save huge amounts of money.

Finally, our new system will significantly reduce the transaction cost, thanks to blockchain, improve the operational efficiency and visibility among the food supply chain, enhance the food safety, and rebuild consumer confidence and market image. I firmly believe that the benefits of our system will be far more than the costs. Enterprises will be willing to invest and share the cost, and consumes will be glad to pay for it.

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