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REVIEW ARTICLE

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Review of operational management in intelligent agriculture based on the Internet of Things

Abstract This review aims to gain insight into the current research and application of operational management in the area of intelligent agriculture based on the Internet of Things (IoT), and consequently, identify existing shortcomings and potential issues. First, we use the Java application CiteSpace to analyze co-citation networks in the literature related to the operational management of IoT-based intelligent agriculture. From the literature analysis results, we identify three major fields: (1) the development of agricultural IoT (Agri-IoT) technology, (2) the precision management of agricultural production, and (3) the traceability management of agricultural products. Second, we review research in the three fields separately in detail. Third, on the basis of the research gaps identified in the review and from the perspective of integrating and upgrading the entire agricultural industry chain, additional research directions are recommended from the following aspects: The operational management of agricultural production, product processing, and product sale and after-sale service based on Agri-IoT. The theoretical research and practical application of combining operational management theories and IoT-based intelligent agriculture will provide informed decision support for stakeholders and drive the further development of the entire agriculture industry chain.

Keywords Internet of Things (IoT), agricultural Internet of Things (Agri-IoT), operational management, intelligent agriculture, precision management, traceability

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1 Introduction

Intelligent agriculture is the advanced stage of agricultural production. It refers to fully utilizing modern information technology (including perception, interconnection, and intelligent techniques) to help agricultural system work efficiently and intelligently, and consequently, achieve the following goals: Strong competitiveness of agricultural products, sustainable development of agriculture, harmony of rural areas, effective usage of rural energies, and sufficient environment protection (Zhou, 2009). Agricultural Internet of Things (Agri-IoT) is the specific application of Internet of Things (IoT) technology to agricultural production, operation, management, and service. Agri-IoT has the following functions: Collects data from agricultural production, logistics, animals, and plants using all kinds of sensors; transfers the collected data through wireless sensor networks, mobile communication wireless networks, and the Internet; and then fuses and processes the collected massive data to realize process monitoring, scientific decision-making, and real-time service during the entire production cycle of agriculture by operating terminals intelligently (Xu, 2013). Agri-IoT technology guarantees agricultural evolution from small scale and decentralized to large scale, intensive, and specialized, transforming the agricultural production mode into a precise, automated, and intelligent one, and promoting the sustainable development of agriculture (Zhao, 2014). Agri-IoT effectively drives the evolution of traditional agriculture to intelligent agriculture.

China has always placed considerable importance on the development of Agri-IoT. In particular, China has promulgated a series of policies and implemented several demonstration projects. Opinions on Accelerating the Transformation of Agricultural Development Modes (The State Council, 2015) were proposed to promote mature and replicable application modes of Agri-IoT, develop precision production modes, and vigorously implement regional pilot projects for Agri-IoT. The 13th Five-Year National Informatization Plan (The State Council, 2016b) explicitly indicated the development of precision and intelligent agriculture to provide innovations for accelerating agricultural modernization. Guidelines on Accelerating the Transformation and Upgrade of Agricultural Mechanization and the Agricultural Equipment Industry (The State Council, 2018) were presented to demonstrate the application of intelligent agriculture and promote the application of information technologies, such as IoT, big data, mobile Internet, intelligent control, and satellite positioning, to agricultural equipment and operations. Opinions on Giving Priority to the Development of Agriculture and Rural Areas and Doing the Work of "Agriculture, Rural Areas, and Farmers" Well (The State Council, 2019) referred to promoting the demonstration applications of Agri-IoT and accelerating independent innovations in intelligent agriculture. The Report of the 19th National Congress of the Communist Party of China suggested the simultaneous development of new industrialization, informatization, urbanization, and agricultural modernization. The development of Agri-IoT technology and intelligent agriculture is important to realize agricultural modernization in China because IoT is the key to solving the issues of low labor productivity and deficient labor force in rural areas (Chang, 2017).

To date, the application of IoT technology to the agricultural field has made certain progress. Agri-IoT software, hardware, and demonstration projects have emerged. The project entitled "70 Years of Agricultural Science and Technology Development in China" (Ministry of Agriculture and Rural Affairs, 2019) points out that China's agricultural science and technology progress has become the dominant driving force in the growth of agricultural and rural economies. Smart agricultural machines and robots, plant protection services by unmanned aerial vehicles (UAVs), Agri-IoT, plant factories, and agricultural big data account for 34%, 45%, 34%, 30%, and 30%, respectively, in the global agricultural technology market.

Although Agri-IoT technology is developing rapidly, experts and scholars have pointed out that the development of Agri-IoT generally remains in the initial stage. Numerous theoretical and technical issues concerning systems, modes, and mechanisms are worthy of further research. At present, IoT application to agricultural production and management is scattered and partial, and its integrated functionality in agricultural development has not been fully explored. Therefore, the entire agricultural management process should be integrated to meet the demand of modern society for a large-scale, intensive, transparent, and specialized agricultural production, which requires crossover research combining Agri-IoT technology with operational management theories (Hu and Sun, 2018). Under this background, a comprehensive review of research regarding operational management in IoT-based intelligent agriculture is expected. Such review can help identify research trends, find existing problems, point out potential hotspots, and promote the theoretical research and practical application of Agri-IoT.

The current work systematically reviews the research status of operational management in IoT-based intelligent agriculture. Relevant literature is obtained from the databases of the Web of Science (WoS) Core Collection and the China National Knowledge Infrastructure (CNKI). The language, document type, and time span in the WoS Core Collection are respectively set as English, unlimited, and unlimited–2019. Meanwhile, the corresponding items in CNKI are set as unlimited, article, and unlimited–2019. A total of 38 records from WoS and 105 records from CNKI are retrieved under the search setting "TS = ([Agriculture* AND Internet of Things AND operation* management] OR [Agriculture* AND IoT AND operation* management])". Among which, 6 articles from WoS and 25 articles from CNKI are excluded because they only tangentially touch upon the search terms. Consequently, 32 records and their 806 references from the WoS Core Collection and 80 records from CNKI are saved in text format for analysis using the Java application CiteSpace.

2 Research status of operational management in IoT-based intelligent agriculture

CiteSpace 5.5.R2 is selected to analyze the full records and cited references of the aforementioned literature. CiteSpace is a Java application used for analyzing and visualizing co-citation networks; it enables analysts to easily perform quantitative and qualitative studies of scientific subject domains (Chen, 2004; 2006). This application was developed by Chaomei Chen in 2004, and it has gradually become a mature and practical tool used for improving our understanding of a research field (Chen, 2006). The cooperation network and co-occurrence analyses of the collected literature are performed using CiteSpace. The corresponding results are presented in Figs. 1–4.

Figure 1 shows the co-occurring research fields. The nodes represent the research fields of the literature, and their size indicates the occurrence frequency of the research fields in the total collected literature. The edges represent co-occurrence relationships among research fields, and their thickness represents co-occurrence intensity. The research fields in the dashed box include business and economics, management, operations research and management science, and business. The number of literature in these research fields is limited, and their co-occurrence intensity with agriculture is weak. This finding demonstrates that minimal attention has been given to the combination of management theories with agriculture.

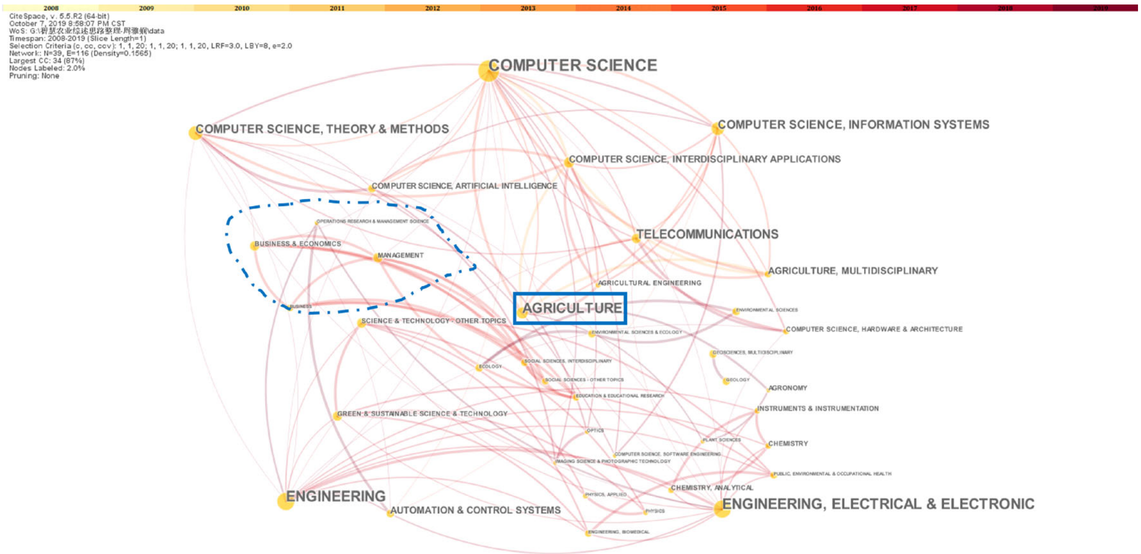

Fig. 1 Co-occurring research fields based on the literature from WoS.

Figure 2 shows the networks of co-authors. Figure 2(a) is generated based on the literature from CNKI, and Fig. 2(b) is based on the literature from WoS. In analyzing these figures, attention should be given to the size of nodes and the thickness of edges. All nodes and edges in the two figures nearly have the same size and thickness, indicating that the number of publications and the frequency of cooperation among all scholars are the same. The networks of these figures are scattered, and all the nodes are small. This finding indicates that no prominent and representative research exists in the field of operational management in IoT-based intelligent agriculture.

Figure 3 shows the network of co-authors' countries. Current research concerned with operational management in IoT-based intelligent agriculture is occurring primarily in China, Japan, and India. Only a few scholars from China and Japan have cooperative relationships.

Figure 4 shows the timeline views of co-occurring keywords. "#" represents the tags of clustering co-occurring keywords, and it indicates research trends and topics in the literature. The timelines visualize the evolution of research trends over time. Figure 4(a) is generated based on the literature from CNKI, and Fig. 4(b) is based on the literature from WoS. The clusters in Fig. 4(a) include agriculture, intelligent agriculture, Agri-IoT, traceability system, precision agriculture, facility vegetable, and application. The clusters in Fig. 4(b) consist of wireless positioning, intelligent irrigation, agricultural product quality monitoring, future direction, big data, intelligent greenhouse monitoring system, and remote sensing Big Agridata. These keywords can be categorized into three: Agri-IoT technologies, precision management of agricultural production, and traceability management of agricultural products. Therefore, the subsequent parts of the review are presented from the three aspects.

Together, the four figures demonstrate that research combining operational management theories with IoT-based intelligent agriculture is a recent focus and still in the early exploration stage.

2.1 Research status of Agri-IoT technologies

In a narrow sense, Agri-IoT refers to a new connection technology among objects related to agricultural production. In a broad sense, Agri-IoT is an integrated network of humans, machines, and objects in a large-scale agricultural system. This technology has four key features: Human–machine–object integration, living body digitalization, application system socialization, and the three whole development concepts, namely, whole-factor, whole-system, and whole-process (Yu, 2013). Agri-IoT technology can integrate data collection, data analytics, and real-time control, enabling operational managers to make informed decisions on their farming operations and transforming operational management from empirical, qualitative, and extensive modes to scientific, quantitative, and intensive modes. From the concepts and characteristics of Agri-IoT, existing research on Agri-IoT technologies mostly involves the following aspects: 1) intelligent object identification and data transmission technology, 2) communication technology between heterogeneous devices, 3) technology for context-awareness, and 4) self-adaptation technology with context changing.

The first aspect focuses on technologies, such as radio frequency identification (RFID), wireless sensor network (WSN), and the Global Positioning System (GPS). Ping

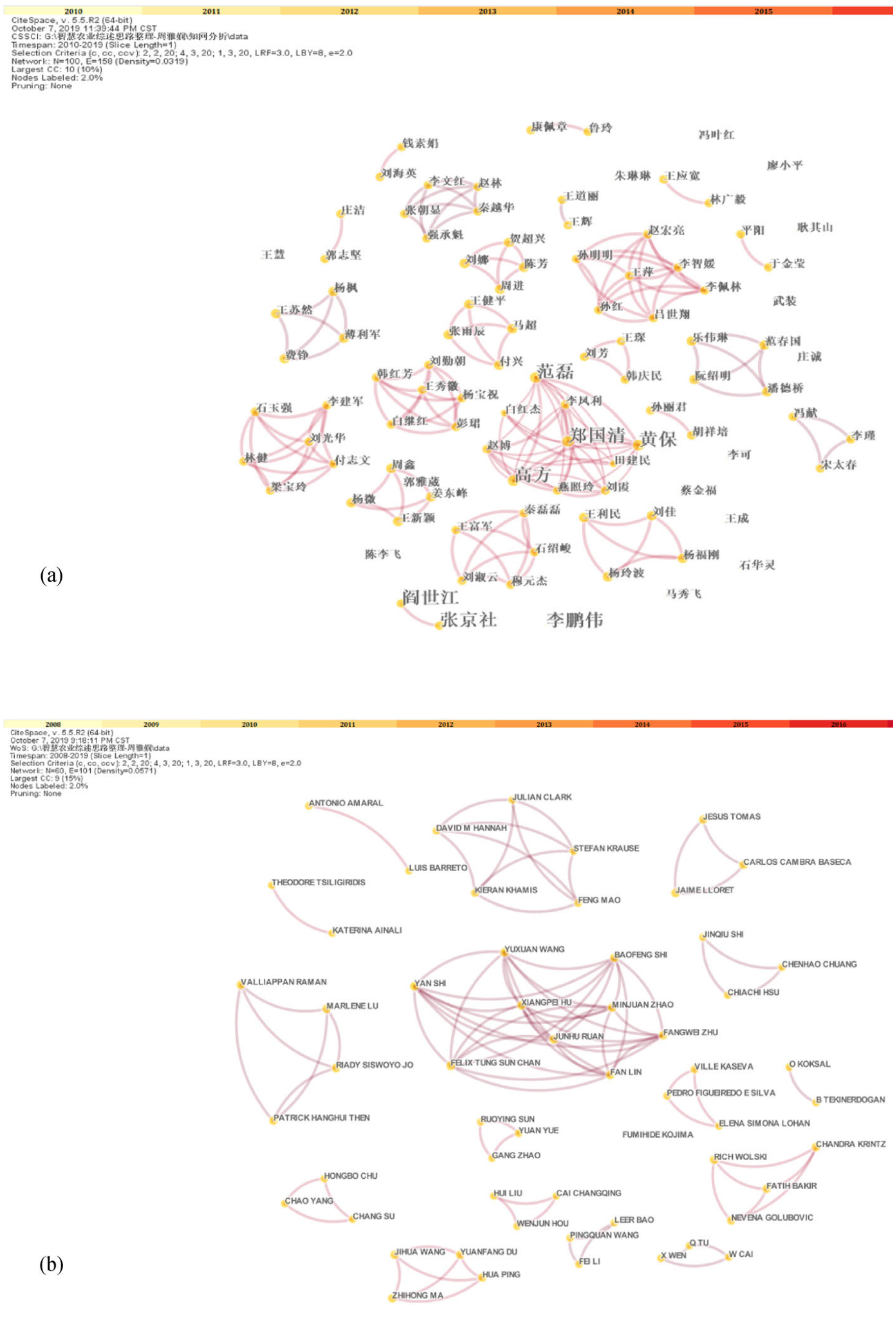

Fig. 2 Networks of co-authors (based on the literature from (a) CNKI and (b) WoS).

et al. (2018) elaborated the aforementioned key technologies used in the agricultural industry and reviewed the recent application of IoT to monitoring the quality and safety of agricultural products. Silva et al. (2018) provided a summary of the current and future trends in wireless positioning. Mao et al. (2019) reviewed the development of low-cost environmental sensor networks over the past 15 years. In addition to these reviews, Liu (2012) introduced the application of WSN to agriculture. Liu et al. (2012) provided a summary of the application of RFID to livestock farming. Zhang et al. (2015) presented a conceptual framework for the application of satellite navigation and positioning technology to precision agriculture. Kojima (2017; 2018) proposed a low-energy and low-latency data forwarding scheme for wireless grid network structures.

The second aspect refers to management information systems. Kaloxylos et al. (2012), Qiu et al. (2013), Wang

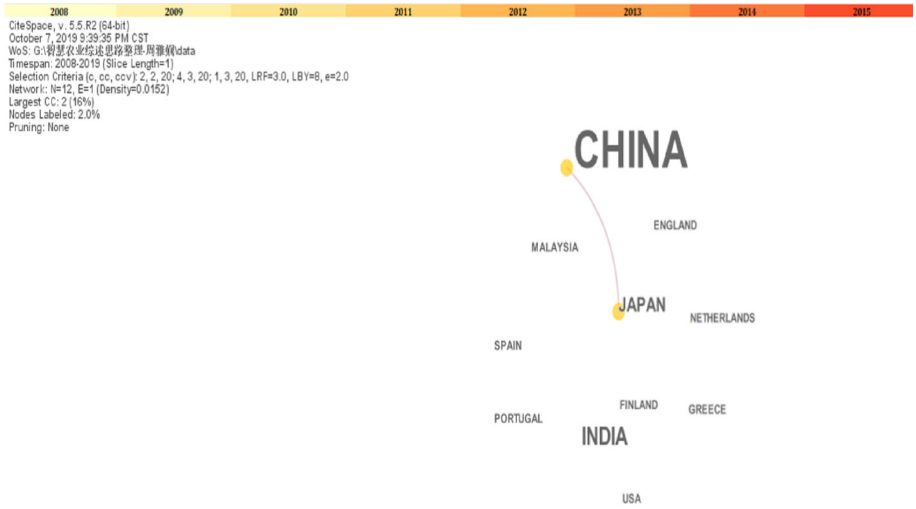

Fig. 3 Network of co-authors' countries based on the literature from WoS.

(2014), Dong and Shi (2016), Su et al. (2018), and Köksal and Tekinerdogan (2019) introduced functional architectures and technological enablers to farming management systems, such as cloud hosting, data management, service ecosystems, and interfaces to networks. Management information systems can be classified into individual and aggregate processes-based systems. Individual process-based systems focus on a major individual agricultural process in a system, such as a production management platform, an environment monitoring system, and a data service platform. Agricultural production management platforms primarily gather various information of a production process to guarantee precise and standard production (Agale and Gaikwad, 2017; Ping and Yu, 2018; Liu et al., 2018; Wang et al., 2018a; Zhang and Yan, 2018a). Environment monitoring systems acquire real-time environmental data, including temperature, humidity, light intensity, and soil nutrients, to provide a suitable environment for agricultural products (Ye et al., 2014; Wang, 2015; Zhang et al., 2016; 2017; Liang, 2016; Tian et al., 2017; Cai et al., 2018; 2019; Zhu, 2018; Bao et al., 2019; Siswoyo Jo et al., 2019). Data service platforms are applied to provide data storage and analysis services to managers (Jiang et al., 2016; Huang and Zhang, 2017; Yue et al., 2018; Fan et al., 2018). Aggregate process-based systems integrate composite agricultural processes in a system. Researchers have attempted to design frameworks of management information systems for the entire process of agricultural products from planting to selling (Ran, 2012; Chen, 2018; Ma, 2018; Wang, 2018; Zhang and Yan, 2018b). Other researchers have referred to several parts of the entire process (Cao et al., 2012; Niu and Wang, 2015; Sun et al., 2015; Zhao et al., 2015; Newlin Rajkumar et al., 2017; Wang et al., 2017). For example, prediction and early warning systems combine prediction and early warning functions, which are applied to production and transportation processes. These systems can predict the yields and diseases of agricultural products (Chen et al., 2018) and generate early warning signals when environmental parameters are predicted to exceed thresholds (Pu, 2016).

The third aspect concerns technologies related to context-awareness and context reasoning. Ruan and Shi (2016) used scenario analysis and interval number approaches to monitor and assess fruit freshness. Krintz et al. (2018) estimated outdoor temperature from CPU temperature for the application of IoT to agriculture. Cambra Baseca et al. (2019) presented a complete implementation of a smart decision support system prototype that automatically learns decision rules from data. Ma et al. (2019) acquired agricultural knowledge with machine learning and image recognition for multi-agent irrigation control.

The fourth aspect is related to agricultural data processing and analytics. Wolfert et al. (2017) reviewed state-of-the-art big data application to smart farming. Mekala and Viswanathan (2017) proposed a new IoT technology with cloud computing and Li-Fi (Light Fidelity) for smart agriculture. Tsiligiridis and Ainali (2018) introduced big agricultural data analytics and its application to food availability.

In addition, some studies have expounded the application of IoT technology to agricultural production and management processes (Li, 2018; Wu, 2018; Guo, 2019; Wang and Wang, 2019). Kong et al. (2016) provided a summary of the development trend of agricultural informatization in seven developed countries and pointed out its deficiencies in China. The first author of this study is currently in charge of a key project of the Natural Science Foundation of China entitled "Context-based online intelligent optimization of scheduling under Internet of Things" (Grant No. 71531002) with the cooperation of the

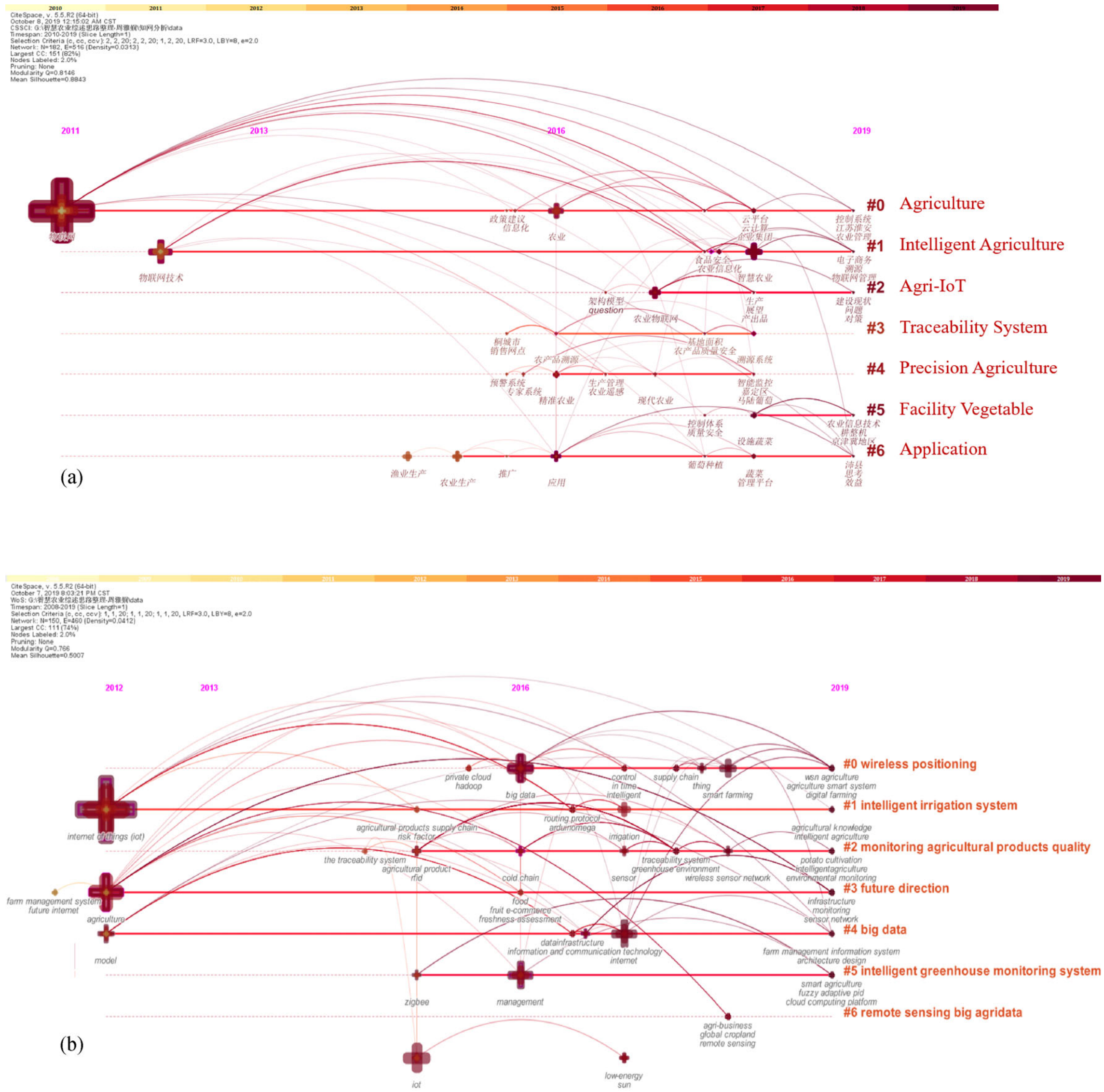

Fig. 4 Timeline view of co-occurring keywords (based on the literature from (a) CNKI (translated version) and (b) WoS).

School of Economics and Management of Northwest A&F University. The project has achieved several successful applications of IoT to the field of agricultural production, such as a water and fertilizer integrated control system, a light supplement system, and a rolling curtain system for IoT-equipped greenhouses (Figs. 5, 6, and 7, respectively) (Ruan et al., 2019). In addition to these applications implemented by the academic community, systematic applications from the commercial community exist. An example is the traceability system based on the IoT blockchain for the Smart Farm developed by JD.com, Inc. (Fig. 8).

Existing research has considerably promoted the application of IoT. However, research on IoT generally remains at the initial stage. Most studies and applications are small-scale, scattered, and partial, and the integrated functionality of IoT has not been fully explored. In particular, the Agri-IoT industry has not yet established unified industrial and technical standards. With regard to IoT technology, the perception and application layers can still be developed. In addition, agricultural production is sensitive to the application cost of IoT technology. All these factors inhibit the application and promotion of Agri-IoT technology (Lu et al., 2017). Therefore, realizing the operations and management of the entire agricultural production by Agri-IoT is necessary to meet the demands of modern society for large-scale, intensive, transparent, and specialized agricultural production.

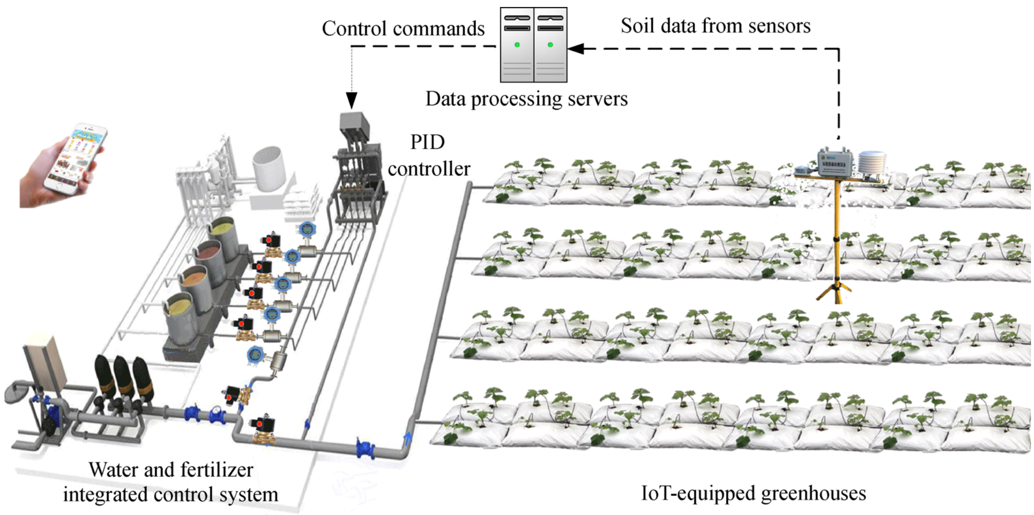

Fig. 5 Water and fertilizer integrated control system for IoT-equipped greenhouses.

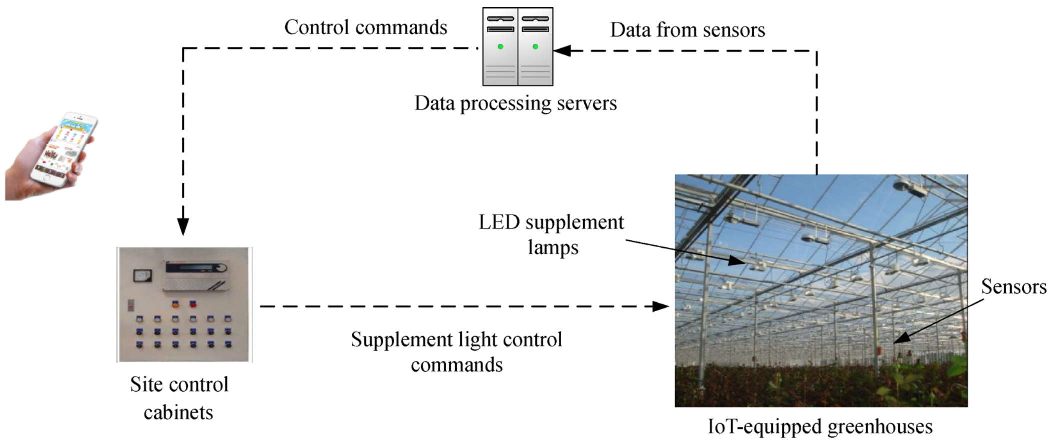

Fig. 6 Light supplement system for IoT-equipped greenhouses.

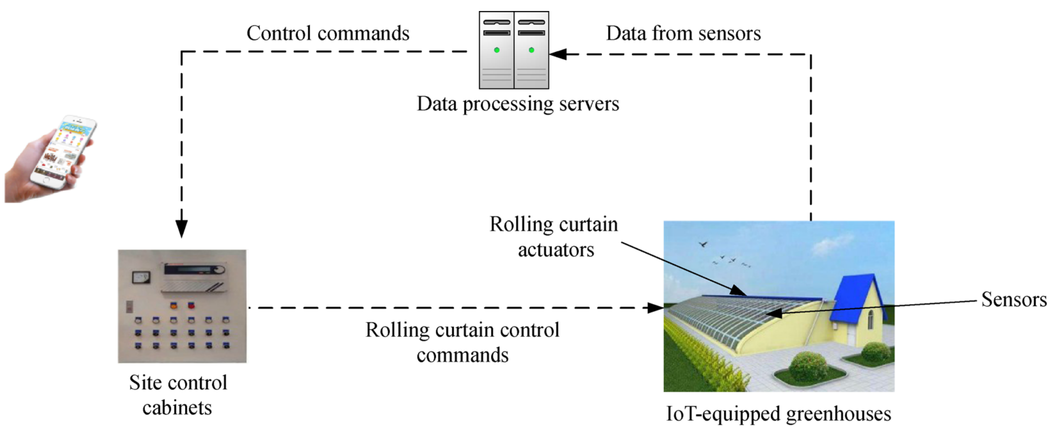

Fig. 7 Rolling curtain system for IoT-equipped greenhouses.

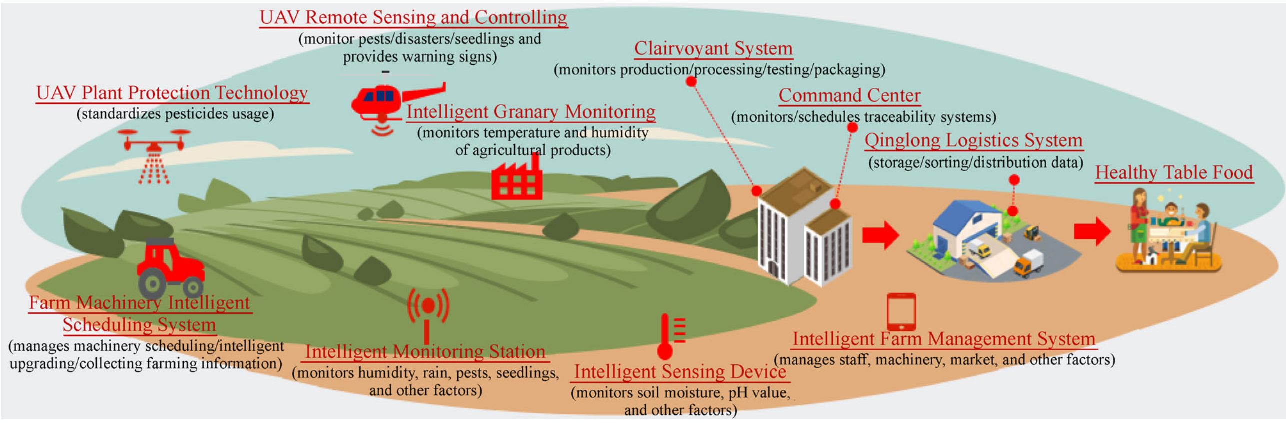

Fig. 8 Traceability system based on the IoT blockchain in JD's Smart Farm.

2.2 Research status of IoT-based precision management in agricultural production

The process of precision management in agricultural production can be elaborated as follows. Central control computers obtain real-time temperature and humidity signals and environmental parameters, such as illumination, soil temperature, CO_2 concentration, leaf moisture, and dew-point temperature, collected by sensors. Then, these computers intelligently and automatically control the on/off switches of exhaust fans, water pumps, or other equipment at the right time to form a closed-loop control system. This process can provide the knowledge base for the intelligent management of comprehensive agricultural information. Existing research on precision management in agricultural production can be categorized into planting and breeding fields.

Research in the planting field includes crop production and vegetable and fruit planting. In Zhejiang Province, the cultivation base of valuable Chinese herbal medicines is established to meet the demands for harsh growing conditions and difficult artificial cultivation techniques (He and Nie, 2015). In Jilin Province, demonstration zones of IoT application are established to explore the application models and mechanisms of IoT technology for field crops (Rural Economic Information Center in Jilin, 2016). In Heilongjiang Province, greenhouses are built for cultivating rice seedlings, irrigating crops, and intelligently monitoring grain storage to change the extensive mode of agricultural operational management (Li, 2017). In soybean production, most existing studies have focused on intelligent decision-making in diagnosing pests and fertilization, but less on irrigation management (Wang et al., 2018b). In Shanghai City, a demonstration site of precision farming for grapes is built, providing real-time monitoring, automatic alarm, and control for the entire growing process (Lu and Kang, 2018; Zhuang and Guo, 2018). In Fujian Province, IoT technology is applied to the entire growing cycle of tomatoes and peppers (Cai, 2019).

Research in the breeding field involves aqua, livestock, and poultry farming. In Henan Province, an integrated IoT framework for fishery is established; this framework is composed of the municipal central station, the county substation, and the terminal station of the breeding base (He and Wei, 2015). In Hangzhou City, a demonstration zone for breeding prawns that monitors and controls water quality online and solves the problem of prawn sensitivity to the water's oxygen content is established (He and Nie, 2015). In the Shangzhuang experiment station of China Agricultural University, a poultry production process management system, which monitors poultry production environment in real time, is constructed (Chen et al., 2015). In Funing County, an intelligent breeding base for pigs is established to obtain real-time environmental information and realize intelligent control, remote visual monitoring, and online diagnosis (He and Nie, 2015). In Shanghai City, several hundreds of standardized ecological livestock farming bases are built (Shen et al., 2016). In Fujian Province, IoT technology is applied to pig production management to reduce the labor intensity of workers and improve piggery environment (Fan et al., 2019).

Considerable research on the combination of planting and breeding for ecological agriculture also exists. In Inner Mongolia, a digital agricultural demonstration project that integrates precision farming, facility, and breeding management system into a unified platform is built (Zhang, 2013). IoT technology is suitable for developing the ecological agriculture mode that combines planting and breeding (Shen et al., 2016). In Jiangsu Province, an intelligent planting and breeding system for rice and shrimp is constructed; this system provides high yield and ecological security to rice and shrimp (Wang, 2019).

Current research on IoT-based precision management in agricultural production mostly emphasizes basic theories and technologies and is limited to experimental projects. However, this subject requires not only theoretical research and experimental projects, but also practicality and production to achieve practical application. The maturity of key products and integrated systems is relatively low, hindering research achievements from transforming into a series of mature products (Liu et al., 2017). An intelligent management information system of high-quality production and standardized planting and breeding is still in an early development stage, and the following issues remain to be resolved. First, some environmental control systems can only supervise but not control. Second, the equipment management system lacks a targeted control strategy, in which some functions are still operated manually. Third, data related to environmental factors are not processed and analyzed in real time, leading to the lack of adverse trend warning, controlling measures based on diagnosis, and feedback based on domain experts' knowledge (Liu et al., 2017). Other problems, including the lack of standard specifications, effective operational mechanisms and models, and interdisciplinary talents, are also expected to be solved urgently.

2.3 Research status of IoT-based traceability management of agricultural products

The construction of a traceability system is an effective measure for collecting and recording information regarding production, circulation, and consumption; tracking the source and direction; investigating responsibility; and strengthening quality management and risk control for the entire process (The State Council, 2016a). A traceability system for agricultural products records and stores all types of relevant information in the entire production, including processing, circulation, and selling, to identify the source of arising problems concerning food quality and safety through a unique identifier and then take urgent measures. Therefore, this system can prevent counterfeit and low-quality products from entering the market, guarantee reliable agricultural products for consumers, and alleviate food safety concerns. IoT applications play a critical role in establishing a traceability system concerning quality and safety for agricultural products based on the principle of origin permit and market access. The essential information of agricultural products is recorded through IoT technologies, such as RFID, 2D codes, and blockchains (Han et al., 2018), which implement traceability in the entire farming management process.

Research on traceability systems for agricultural products can also be classified into the planting and breeding fields. Research in the planting field involves vegetables and arable farming. In the sericulture industry, the data of each batch of mulberry leaves are stored in the database and RFID tag, helping technicians in identifying the causes of an outbreak of silkworm disease and the quality control department in making an inspection; in this manner, consumers can accurately determine the conditions of their products (Zhou et al., 2015). In Jilin Province, 2D code systems are established to keep track of the planting, processing, monitoring, and marketing information of crops (Rural Economic Information Center in Jilin, 2016). In Heilongjiang Province, agricultural production, quality management, product monitoring, product certification, and other elements are integrated into a traceability system for quality and safety supported by IoT (Li, 2017). In Shanxi Province, a management platform embedded with expert decision-making modules is developed for safe vegetable production (Zhang and Yan, 2018a). In Heilongjiang Province, the traceable area of agricultural products reaches nearly 2×10^8 m^2 with the help of a 2D code technique (Jiang et al., 2018). Fu et al. (2018) proposed a vegetable traceability prototype based on the mode of community support agriculture that integrates mobile Internet, the 2D code technique, and Web technology. Research in the breeding field includes fishery and livestock farming. In Jiangsu Province, a traceability system based on the quality monitoring of rice and shrimp is established, which realizes forward and backward tracking through a 2D code (Wang, 2019). In Fujian Province, an operational model of the entire industrial chain for hogs is constructed, wherein a food safety system can be tracked from the farming base to the table of consumers (Fan et al., 2019).

In addition to the aforementioned traceability systems in the planting and breeding fields, a full supply chain traceability system is available for agricultural products sold online via JD.com. These products are from JD's Smart Farm, which has established an IoT-based business model for tracing products at any time and section in the entire supply chain to guarantee high product safety and quality (Fig. 9).

For the adoption and further development of traceability management, several issues that inhibit its development are expected to be addressed. First, no unified definition of agricultural traceability standards exists. The current situation of traceability management is in a state of fragmentation, and traceability norms in different regions are inconsistent and incompatible. A normative traceability system based on unified agricultural standards should be established. Second, traceability systems in some countries are not compliant with international standards; this situation is detrimental to the export of agricultural products. Third, the promotion of traceability technology is insufficient and inadequate. Numerous companies still record information manually by human observers, disregarding the speed and regularity of a traceability system.

3 Conclusions and future research directions

Rapid developments in Agri-IoT are driving the transformation of modes in traditional agricultural organization and production from small scale that relies on isolated machinery and small workshops to large scale that focuses

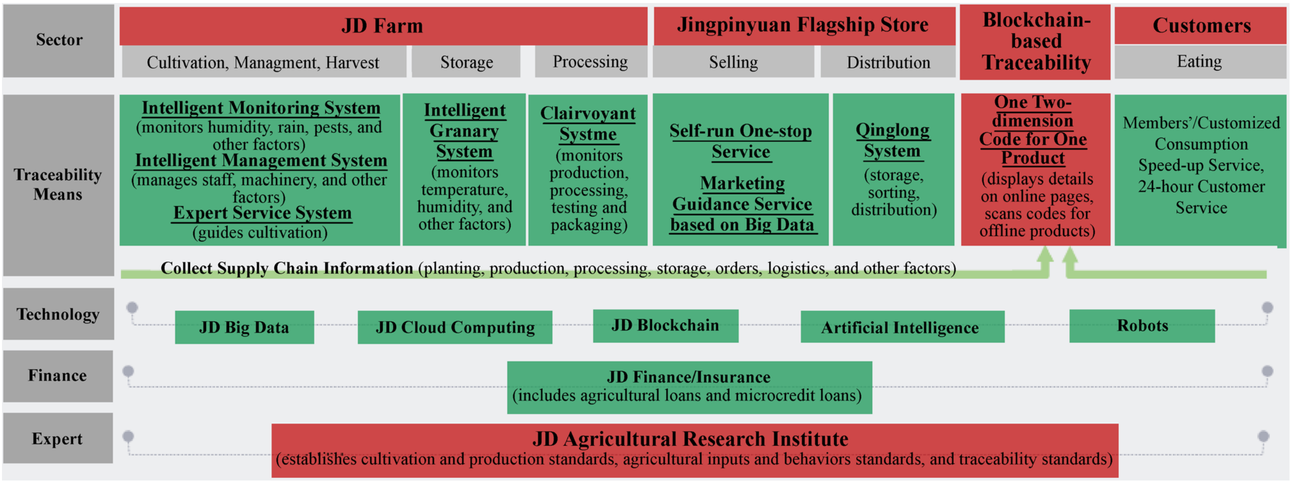

Fig. 9 Traceability system in JD's Smart Farm.

on modern information technology. To achieve the steady and sustainable development of modern agriculture, the adoption of advanced management methodologies that are suitable for the use of a large number of automated, intelligent, and remotely controlled equipment, and big agricultural data management is urgent. A systematic and in-depth study of operational management in the application of IoT technology will be beneficial for the cross-research of modern information science and advanced management theories and for realizing the sustainable development of well-structured agriculture.

Research on operational management in IoT-based intelligent agriculture integrates management processes, such as planting, production, processing, selling, after-sale service, and tracking (Bo et al., 2019). As shown in Section 2, only a few scientific publications regarding operational management in IoT-based intelligent agriculture are available. Most existing theoretical research and practical applications of operational management focus on three aspects: Technological design, precision management of agricultural production, and traceability management of product quality and safety. Although each aspect is an integral part, the integration of all farming management processes is still necessary. That is, research concerning a single part of the agricultural product supply chain of Agri-IoT is small-scale, scattered, and incomplete, and the integrated functionality of IoT would not be fully explored. In future research, investigating the operational management of IoT-based intelligent agriculture based on the entire agriculture industry chain is expected. Several unexplored research directions are recommended as follows.

• Operational management of agricultural production based on Agri-IoT. First, an IoT architecture for collecting and monitoring massive highly heterogeneous data should be designed. Real-time environmental data (e.g., temperature, humidity, and CO_2 concentration) and artificial operational data (e.g., irrigation and application of fertilizer) exhibit the characteristics of high heterogeneity, long-distance data transmission, and high accuracy requirement. Simultaneous communication across a large number of sensors is likely to bring congestion and even poses the risk of paralysis to servers. As sensors proliferate and data volumes grow, establishing a well-structured IoT framework suitable for the collection, transmission, and storage of these data from different sources is expected. Second, knowledge fusion and discovery methods for multisource heterogeneous data should be developed. Massive data are processed using data mining models, which are applied to accurately assess and diagnose the condition of agricultural products. Lastly, exploring intelligent decision-making methods of precision is valuable. The precision management of agricultural production requires real-time analysis of the growth status of agricultural products, combines their growth rules with agricultural experts' knowledge, establishes intelligent decision-making models, and obtains the corresponding results to guide practical operations in real time.

• Operational management of agricultural product processing based on Agri-IoT. On the one hand, the context-based online processing-and-distribution collaborative scheduling for agricultural products under IoT should be resolved. The processing and distribution of agricultural products are time-critical, and every process should cooperate closely. The scheduled objects exhibit continuous and dynamic states. The essential problem of online intelligent collaborative optimization is how to drive the steps of picking, processing, sorting, packaging, and distribution to become an intelligent and continuous process in the context of IoT. On the other hand, optimizing the organizational architecture of agricultural product processing is necessary. The high intelligence of Agri-IoT improves the organizational efficiency of the agricultural supply chain and reduces labor cost. The intelligent business process requires high robustness and low risk. Therefore, comprehensively considering various constraints, establishing a trade-off among various elements, and finally presenting a suitable organizational architecture are expected.

• Operational management of agricultural product sale and after-sale service based on Agri-IoT. The primary task is to explore quality management and traceability methods for the entire life cycle of agricultural products. First, a food quality and safety management system based on monitoring data in the context of Agri-IoT should be adapted to the characteristics of the agricultural product supply chain. Second, proposing marketing models for agricultural products in the context of IoT is valuable. With regard to designing marketing models, the current sale status of agricultural products and the features of Agri-IoT should be considered. Third, several constraints, such as cutting down the redundant intermediate links of circulation, improving the circulation efficiency of supply and demand information, and reducing the cost of circulation should also be considered. Lastly, the value network and its value analysis in the application of Agri-IoT are expected to be emphasized. In summary, the "IoT + blockchain + value creation" from JD's Smart Farm is now an initiative agricultural business model that has the potential to realize all the aforementioned aspects to guarantee the safety and quality of agricultural products. However, the establishment of Agri-IoT requires participation and collaboration among different stakeholders. Consequently, clarifying the relationships, different behavior, and service strategies among these participants in the same value network is an important issue that should be addressed.

Unifying industry standards, improving the compatibility and connection of every link of the Agri-IoT supply chain, and realizing real-time data analysis are the prerequisites in conducting the aforementioned research. The operational management methods for IoT-based intelligent agriculture are expected to be proposed based on knowledge in data mining, intelligent decision-making, context-based modeling, information science, network optimization, and value analysis. Considerable effort should be exerted in designing and establishing a systematic and adaptive platform that integrates modules, such as production management, online intelligent processing-and-distribution collaborative scheduling, traceability management, and e-commerce. The theoretical research and practical application of combining operational management theories with IoT-based intelligent agriculture are expected to grow rapidly, which can provide informed decision support for stakeholders and boost the comprehensive development of the entire agriculture industry chain.

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