IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

SPECIAL SECTION ON BIG DATA TECHNOLOGY AND APPLICATIONS IN INTELLIGENT TRANSPORTATION

Received September 23, 2019, accepted September 29, 2019, date of publication October 2, 2019, date of current version October 16, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2945078

Operation Mechanisms for Intelligent Logistics System: A Blockchain Perspective

YONGGUI FU[1] AND JIANMING ZHU[2]

[1]School of Information, Shanxi University of Finance and Economics, Taiyuan 030031, China
[2]School of Information, Central University of Finance and Economics, Beijing 100081, China

Corresponding author: Yonggui Fu (fygzcd@163.com)

This work was supported by the National Social Science Fund of China under Grant 18BTQ083.

ABSTRACT Aiming at the current problems of security threats and privacy leak risks in the operation process of related data of intelligent logistics system, and the operation of system lacking of supervision and traceability, this paper proposes to use blockchain technology to resolve these problems. A scheme on applying blockchain in intelligent logistics system is proposed, including operation principle, consensus authentication mechanism, and data storage and access mechanism. By introducing and analyzing the related big data of intelligent logistics system, improving the scientific, rationality, and intelligence of the decision. The basic characteristic of blockchain is traceability. By constructing algorithm models, proposing the realization principles of consensus authentication mechanism. For different events, different ''multi-authentication centers'', intelligent contracts, and blockchain systems are constructed, improving the efficiency and supervision of the operation of intelligent logistics system. By constructing the correlations between the fundamental data that corresponding to different blockchain, and the correlations between the fundamental data that corresponding to the same blockchain, making the related data easier to collect and analyze. By constructing the storage and access mechanism, ensuring the security and confidentiality of the operation data of intelligent logistics system. This paper has provided thought for the application research of intelligent logistics system based on blockchain, and has positive reference value and guiding significance to the development of blockchain application research.

INDEX TERMS Intelligent logistics system, blockchain, operation mechanisms, big data.

I. INTRODUCTION

With the emergence and development of the technologies as artificial intelligence, Internet of things, big data, data communication, etc., intelligent transportation system has been concerned, applied and researched gradually by various industries. The application of intelligent transportation system can not only save human and material resources, but also greatly improve the accuracy, automation and coordination of traffic vehicle dispatch, logistics distribution. Intelligence is the strong guarantee for the connection between transportation system and other systems, and intelligent transportation system is the inevitable trend of the development of information technology and artificial intelligence.

Intelligent logistics system is a typical application of intelligent transportation system. Intelligent transportation system can provide intelligent transportation tools, accurate distribution route, distribution time and distribution strategy for intelligent logistics, with the help of geographic information system and satellite system, intelligent logistics system can provide scientific and reasonable emergency response strategy to the changes of external environment. Intelligence logistics resolves the problem of low logistics efficiency caused by information asymmetry between different nodes and subjects in traditional logistics sections.

The operation of intelligent logistics system cannot divorce the support of big data, these big data include not only the big data outside intelligent logistics system, but also the big data formed by the data that produced and accumulated in the operation process of intelligent logistics system. For example, intelligent logistics system needs to use the big data of transportation route and the big data of transportation environment acquired by satellite system to make the real-time response decision for logistics distribution, and intelligent logistics system needs to use big data that produced by system operation to evaluate and analyze the system

The associate editor coordinating the review of this manuscript and approving it for publication was Sabah Mohammed.

operation efficiency, to analyze the credit of demanders, and to make efficient logistics distribution plan, etc. Because of involving vehicle dispatch, in-transit transportation management, and emergency response, etc., and involving radio frequency identification technology, geographic information system, global positioning system, and sensor devices, etc., and the related suppliers and demanders have great variability and large regional span, so, the data structure and types of the related big data of intelligent logistics system are also diversified and complex. Therefore, how to collect and analyze the related big data of intelligent logistics system, and manage the analysis result data, becomes a difficult task.

In fact, big data face not only the problems of retrieval, analysis and storage, but also the problems of transmission and application security. So, how to effectively obtain valuable data from big data, ensure the acquired data are not maliciously changed, destroyed and leaked privacy information in the process of transmission and storage, and ensure the supervision and traceability of the operation process of acquired data, is the key to the application of big data, for intelligent logistics system, it is also the premise and guarantee of the rational and effective operation. At present, there are many research results on big data retrieval, analysis, and storage, such as Feng *et al.* [1] proposed a personalized video retrieval system to facilitate users to retrieve the required video from big data. Yao [2] researched the key technologies on audio big data retrieval. Wu and Ji [3] compared the performance and characteristics of MapReduce and Spark being used in big data analysis from different perspectives. Sim [4] proposed a big data analysis method aiming at intelligent manufacturing system. Wang *et al.* [5] summarized the research progress of artificial intelligence being used in big data analysis. Lv *et al.* [6] proposed a big data secure storage scheme based on compression and encryption technology. By analyzing currently related research results on retrieval, analysis and storage of big data, it can know the current research results haven't put forward the mode of systematic management on big data, there lacked of effective connection for the retrieval, analysis, and storage of big data, and lacked of correlation construction between different types of related data, so it is difficult to collect related data centrally for a certain retrieval topic, and the intelligence level of big data management is insufficient. In the era of big data, the security problems of network data transmission and storage are more prominent, so the security and privacy protection of big data have become a key issue in the field of big data research, and a lot of research results have been produced, such as, Rubinstein [7] analyzed the impact of big data to privacy protection from a theoretical point of view. Feng *et al.* [8] discussed the related technical challenges on big data security and privacy protection, and explained that big data has become an important way to solve security problems while introducing security problems. Chen *et al.*[9] sorted out the key technologies of big data security protection. By summarizing the current research results on big data security and privacy protection, it can know the research results in this field are mainly the application of the security technology and privacy protection technology of small-capacity data in big data environment, and because at present these technologies can not completely solve the security and privacy protection problems of small-capacity data, so, in application the security protect ability of these technologies to big data is limited.

To the application of related big data of intelligent logistics system, it needs to collect corresponding data quickly from different data sources of related big data in accordance with specific requirements, and analyze and handle them quickly. Moreover, the intelligent logistics system needs to ensure the authenticity and operation security of the collected data, and to ensure real-time recording and traceability of the collected data, while the current operation management technologies and security technologies of big data obviously cannot fundamentally solve these requirements, so the effective operation of intelligent logistics system cannot be guaranteed for a long time. If we can record the operation process of related decision support data of intelligent logistics system in real time and dynamically, realize the traceability of data operation process, construct the correlation of the collected data from related big data, ensure the collected data are not changed and destroyed in the operation process, and adopt corresponding privacy protection measures, then the effective operation of intelligent logistics system will have the ability of guaranteeing data authenticity, and the operation process of intelligent logistics system will be more efficient. Obviously, these can all be solved by blockchain technology.

II. RELATED WORKS

In this section, we introduce the related works of this paper from three parts as: ''the composition and structure of blockchain'', ''application research status of blockchain'', and ''the sources of big data and application value of blockchain''. Therein, in the part of ''the sources of big data and application value of blockchain'', we have introduced the data sources of the related big data of intelligent logistics system, and introduced the value of blockchain technology applying in intelligent logistics system.

A. THE COMPOSITION AND STRUCTURE OF BLOCKCHAIN

Blockchain [10], [11] is a distributed accounting technology constructed in network system, and it is also a database. Blockchain was introduced in November 2008 along with Bitcoin. The most important characteristics of blockchain are which synthesizes the technologies or methods as hash algorithm, digital signature, timestamp technology, intelligent contract, and consensus authentication mechanism etc. to construct a data authenticity proof system in blockchain system, and realizes the anonymous management of network data providers' and visitors' identities (privacy protection). The composition and structure of blockchain is shown in Fig. 1.

In Fig. 1, the fundamental data (such as Data1, Data2, Data3, Data4) and blockchain are stored respectively. In fact, if the capacity of fundamental data is less, we can also

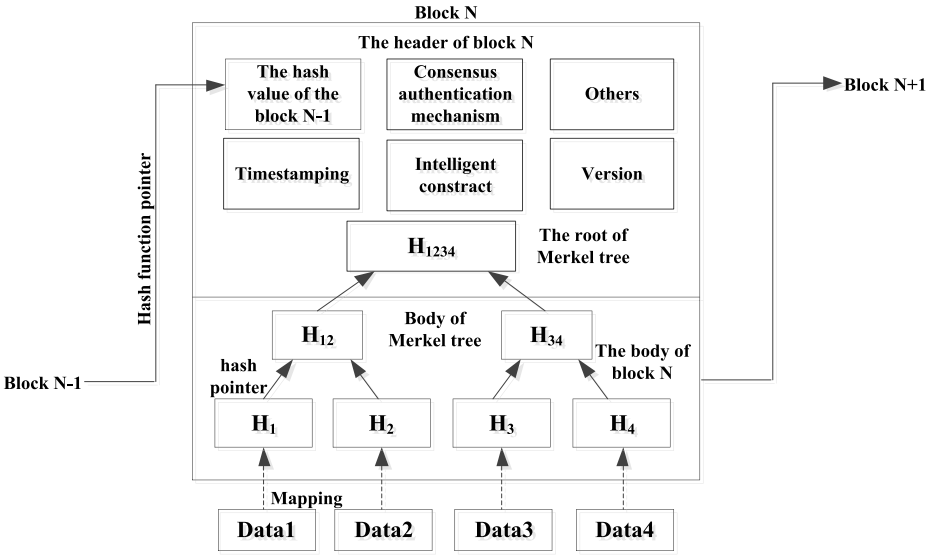

FIGURE 1. The composition and structure of blockchain.

choose the form of storing fundamental data together with the body of Merkel tree in the body of block. The mapping relationships between the fundamental data and its hash values (stored in block) are established. Different blocks are connected by hash function pointers, and the hash value of the precursor block is recorded by its subsequent block.

B. APPLICATION RESEARCH STATUS OF BLOCKCHAIN

Since 2015, the applications and researches of blockchain have developed rapidly. Academic circles have paid extensive attention to the value of blockchain and the impact of the credit system basing on blockchain to the network society, industry circles have begun to construct application systems in different fields and develop corresponding products. At present, blockchain has already gone through the era of digital currency, and acquired very large progress in the aspect of construction of intelligent contract. The next step will be the construction of blockchain application architecture in different fields and the interconnection of blockchain systems in different fields to build a credit society. Although the construction of blockchain application architecture and product development in different fields are still in the initial stage, but its strong vitality and good application development makes people believe that blockchain will be the basic technology to build the world's credit network system in the future.

At present, almost all governments around the world have paid great attention to the blockchain. The countries as China, the United States, the United Kingdom, France, Russia, etc. have established plans, regulations, and policies that rise to the national strategic development for the blockchain. Many countries have jointly established alliance organizations based on the blockchain (such as financial blockchain alliance organization R3 CEV), and have jointly developed blockchain products for cross-border applications (such as OKLink, a value transmission network built on blockchain technology). The widest application and fastest development area of blockchain is the financial field, and a large number of financial products based on blockchain have been produced, such as Bitcoin, Litecoin, Zcash, etc. In addition, blockchain has also achieved great application research progress in other fields, such as copyright protection (e.g. Custos, Blockai), e-commerce (e.g. Purse.io, Colu), supply chain (e.g. WuChain in China, Bubi blockchain in China), anti-counterfeiting notarization (e.g. Factom, Civic), medical health (e.g. Dentacoin, MediBloc), and Internet of things (e.g. Launch Key, Tilepay). Many countries have also begun to formulate cross-border blockchain standard systems and cooperation plans at the national level. Companies that specialized in the development of blockchain have also been established in various countries, by the end of March 2018, the number of companies with blockchain as their main business in China had reached 456. In the application of blockchain in specific fields, adaptive adjustments have been made on the basis of maintaining the principle of its main architecture, therein, many products have different operation mechanisms from the classical Bitcoin blockchain [12] and Ethereum blockchain [13], [14], which is precisely where the vitality of blockchain lies.

As an application technology system, compared with industry circles, the development of blockchain in academic circles is relative lag, according to the content and characteristics of blockchain research results, the current blockchain research results can be divided into four categories as: the research on social impact and application value discussion of blockchain, the design of technical principle, the construction of application architecture, and product development.

1) THE RESEARCH ON SOCIAL IMPACT AND APPLICATION VALUE DISCUSSION OF BLOCKCHAIN

Research on the social impact and application value dicussion of blockchain is generally primary research, these researches are intended to analyze the application vitality of blockchain in specific scenarios and the feasibility of blockchain system construction in specific scenarios, and discuss the application value of blockchain. Such as, Feng [15] proposed out that with the advent of blockchain database era, the quality and reliability of big data will rise to an undeniable level. Goertzel *et al.* [16] analyzed the application value of blockchain in digital currency field. Hughes *et al.* [17] analyzed the influences of blockchain in several social environments.

2) THE DESIGN OF TECHNICAL PRINCIPLE

The research results of the design of blockchain technology principle usually focus on one aspect of blockchain technology system, including the construction of intelligent contract, the design of consensus authentication mechanism, and the application of classical blockchain technology in some a field, etc. Such as, Gao [18] proposed a data encryption algorithm based on blockchain for e-commerce platform. Fu and Zhu [19] designed the intelligent contract for blockchain applying in risk management of some a category supply chain. Huh and Kim [20] proposed a consensus algorithm based on blockchain for renewable energy transaction system.

3) THE CONSTRUCTION OF APPLICATION ARCHITECTURE

The research results of the construction of blockchain application architecture usually aim at the application scenarios of blockchain, design the application modes and implementation principles of blockchain in specific fields. At present, this kind of research is the mainstream of blockchain research, and also indicates that people have developed blockchain from understanding and analysis stage to landing stage, which is also the primary stage of blockchain credit society construction. Such as Fu *et al.* [21] constructed the application architecture of blockchain for CPS information security risk evaluation system. Yu *et al*. [22] proposed a sharing and exchange model for government information resource. Han *et al.* [23] constructed a platform framework based on blockchain for intelligent distribution electricity transaction.

4) PRODUCT DEVELOPMENT

The research of blockchain product development intended to introduce blockchain products and analyze the performance of blockchain products. The research was based on existing products that have been successfully developed or products that have been constructed models. The product or model such as CoinParty [24], Certcoin [25], [26], KeyChains [27], ModelChain [28], etc. These products or model systems were based on classical blockchain, and were improved according to the specific application environment, to form specific application products.

Blockchain can promote the intelligence of logistics system, traffic system and transportation system. At present, the application research of blockchain and the application research of intelligent logistics, intelligent traffic, and intelligent transportation are all still in the elementary stage, so the research results of the combination of blockchain and intelligent logistics, intelligent traffic, or intelligent transportation can hardly be found, although some scholars have provided the research results in the fields of blockchain in logistics, traffic, or transportation (such as [29]–[31]), but these research results failed to provide a complete operation system of blockchain in these fields, moreover, these research results did not require application fields had high intelligence, and lacked of research on big data applications. Therefore, this paper put forward the thought of applying blockchain technology to intelligent logistics system, by introducing and analyzing intelligent logistics system related big data, constructing intelligent contracts, consensually authenticating and analyzing the operation data of intelligent logistics system and forming decisions, to realize the authenticity guarantee of data of intelligent logistics system, and improve the scientific of decision. At the same time, this paper put forward the storage and access mechanism of the operation data of the intelligent logistics system based on blockchain, constructed the correlation between the data, and constructed the confidentiality management mechanism, to ensure the security of the data and improve the retrieval efficiency of data.

Modeling can greatly improve the descriptive ability to the research content, and promote the understanding of readers to the research content, such as [32]–[35]. Modeling is applied widely in different fields with various forms. In view of the research characteristics of this paper, we construct principle models and algorithm models to illustrate the operation process and realization principle of the system.

C. THE SOURCES OF BIG DATA AND APPLICATION VALUE OF BLOCKCHAIN

Classified by business characteristics, intelligent logistics system can be divided as intelligent production logistics system, intelligent transportation logistics system, intelligent sales logistics system, intelligent storage logistics system, etc. The intelligent logistics system researched in this paper refers to intelligent transportation logistics system, and this paper related research results and research conclusions have same application value and guidance significance to other types of intelligent logistics systems.

The operation of intelligent logistics system needs to implement goods distribution according to the order condition from demanders, and needs to formulate distribution decisions by checking distributors' goods supply ability. The implementation of logistics process needs the support from vehicle management system, traffic management system, in-transit transportation monitoring system, emergency response system, decision support system, and logistics evaluation system etc. Therein, order management system is used

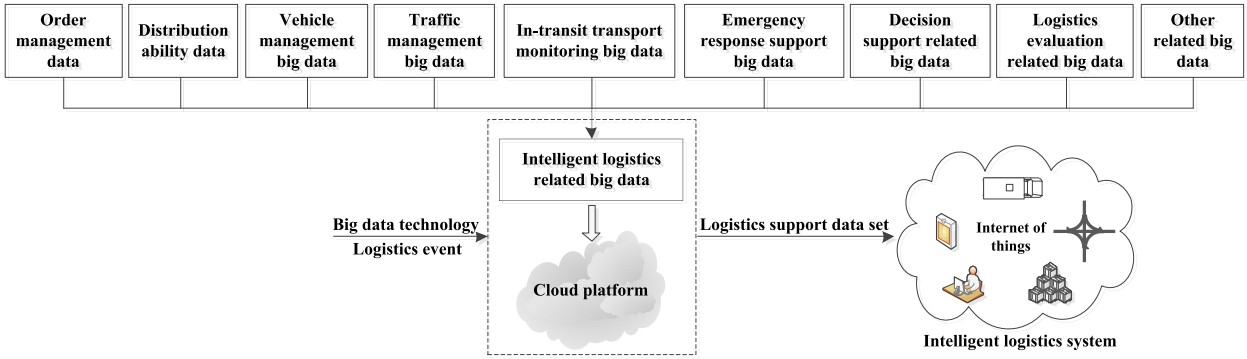

FIGURE 2. The sources and status of the related big data of intelligent logistics system.

for acquiring and managing the information of the category, amount, time, price etc. of order goods of the demanders. The distribution decision management system is used for analyzing the distribution ability of the distributor according to the order of the demander, and forming the distribution decision. The vehicle management system is used for supervising the vehicle dispatch and in-transit status, etc. The traffic management system is used for providing the information of the route and the road conditions of logistics distribution. The in-transit transportation monitoring system is used for providing the real-time status information of logistics process. The emergency response system is used for responding to the emergencies encountered in the logistics process. The decision support system is used for recording the decision-making process and decision result data for each event in logistics process, for guiding the implementation of the subsequent decisions. Logistics evaluation system is used for evaluating each section of logistics process and producing evaluation results, which can be used as the basis for assisting decision-making of different events in intelligent logistics system. In addition, the intelligent logistics system also needs the support from the infrastructures as Internet of things, cloud computing and satellite navigation, etc., here we will not explain in detail. The operation of intelligent logistics system needs to analyze the related data of its dependent subsystems and form decision dependent data, then the decision dependent data are operated and formed decision result data, the forms of these data are different, and the analysis process and management process are also different, but these data are correlative in the process of data being produced and the operation of intelligent logistics system. The data capacity of some subsystems have already reached the scale of big data, and the data capacity of some subsystems still belongs to small capacity, and the data of all these subsystems constitute the related big data of intelligent logistics system. Basing on the above analysis, the sources and status of the related big data of intelligent logistics system are shown in Fig. 2.

Applying blockchain in intelligent logistics system, recording the data that support the operation of intelligent logistics in the blockchain system, constructing correlation abstract information between the recorded data and external big data and data sources, and the abstract information will also be recorded in the blockchain, to ensure the authenticity and traceability of the recorded data. For different types of events of intelligent logistics system, different blockchain systems should be constructed, and virtual correlation of the data of different blockchain systems should be constructed, for centralized analyzing and applying the related data conveniently. Blockchain will also promote the group authentication and decision of the operation of intelligent logistics system, avoid the decision dependent data in intelligent logistics system being destroyed, changed and leaked in the process of transmission and storage, realize the dynamic real-time monitoring and early warning to the malicious operation and intervention behavior in the operation of intelligent logistics system, and realize the group analysis and common decision-making of the events in intelligent logistics system. Because the classical blockchain technology has some shortcomings in data confidentiality, so, this paper proposes to construct the storage and authorization access mechanism for the related operation data of intelligent logistics system based on blockchain. The related data (event data, event decision dependent data, the abstract information of big data and data sources that corresponding to event decision dependent data, decision result data, etc.) produced in the operation of intelligent logistics system have supporting function to the further operation of the intelligent logistics system (these data are stored in decision support system as required), which also improves the efficiency of data retrieval, data analysis, and data application decision of intelligent logistics system.

Basing on the above analysis, the main value of applying blockchain to intelligent logistics system is shown in Fig. 3.

III. METHODOLOGY

In this section, we have proposed a scheme of blockchain technology applying in intelligent logistics system, including three parts as: ‘‘operation principle’’, ‘‘consensus authentication mechanism’’, and ‘‘data storage and access mechanism’’. Therein, in the part of ‘‘operation principle’’, by constructing process model we have introduced the operation principle of

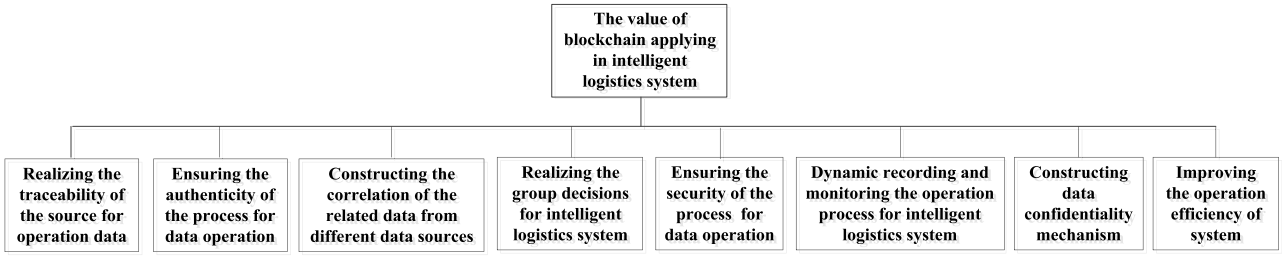

FIGURE 3. The main value of applying blockchain to intelligent logistics system.

blockchain technology applying in intelligent logistics system. In the part of ''consensus authentication mechanism'', by constructing algorithm models we have introduced the realization principle of consensus authentication for data authenticity and intelligent contract operation results. In the part of ''data storage and access mechanism'', we have introduced the storage and access methods of the data that have been operated in the intelligent logistics system based on blockchain. In this section, we have used the form of total-part to illustrate the operation process of related data of the intelligent logistics system based on blockchain.

In the intelligent logistics system based on blockchain, because the logistics process needs the support of system data from order management system, distribution ability management system, vehicle management system, traffic management system, in-transit transportation monitoring system, emergency response system, decision support system, and logistics evaluation system etc., and the data capacity of these systems has already reached the capacity of big data, so, it is necessary to construct a big data analysis center to collect and analyze the data of these data sources centrally, and to ensure the security and confidentiality of the data handling and data submission of the big data analysis center(The security and confidentiality can be realized by applying blockchain in the process of data handling and data submission of the big data center, or can be realized by the authoritative agencies constructing big data analysis center and supervising its operation, to ensure the credibility of big data analysis center.). In addition, although the data capacity of order management system and distribution ability management system is small, the data can also be collected and analyzed by big data analysis center. Therefore, this paper proposes to construct a big data analysis center to handle the related big data of the intelligent logistics system.

Due to the diversity and complexity of the events in intelligent logistics system, in the operation process of intelligent logistics system, basing on different types of events (such as order requirement, distribution decision, vehicle dispatch, traffic road condition analysis, emergency response, etc.), when event data and the analysis result data from big data analysis center (decision dependent data) enter into the process of analysis and decision, different blockchain system is constructed according to the type of event. In the operation process, the analysis result data, the abstract information of big data and data sources that corresponding to the analysis result data, and event data, etc. are broadcast, authenticated, recorded and stored with decentralized style in the blockchain. The fundamental data (the event data, the analysis result data, the abstract information of big data and data sources that corresponding to the analysis result data, and decision result data produced in the operation of the system, etc.) that corresponding to different blockchain are respectively stored in some storage bodies different from blockchain. Because the events of intelligence logistics system are related, so the fundamental data that corresponding to different blockchain are also related. Therefore, the fundamental data corresponding to different blockchain will be constructed virtual correlations, and the fundamental data that corresponding to the same blockchain will also be constructed virtual correlations.

Because of the requirement of industry and confidentiality of intelligent logistics system, this paper proposes that by the belonging industry of intelligent logistics system to appoint different authoritative bodies according to the types of events, and the different authoritative bodies (formed by government agencies, industry associations or logistics nodes, etc.) form ''multi-authentication centers'', ''multi-authentication centers'' authenticate the data transmission, data computation and decision-making in the operation process of intelligent logistics system. Because of the complexity of the operation and decision process of the intelligent logistics system, so, for the same type of events, intelligent contract is constructed, and the intelligent contracts corresponding to different types of events are different, and the intelligent contracts are operated and realized the group decisions on logistics events by ''multi-authentication centers''. In order to further ensure the confidentiality of data, this paper proposes that ''multi-authentication centers'' only store the operation blockchain, and not store accounting fundamental data, and the accounting fundamental data are stored with decentralized style in some cloud spaces of cloud platform.

A. OPERATION PRINCIPLE

In the operation process of intelligent logistics system, specific logistics events occur. According to the specific nature of events, the system will propose data requirements to the big data analysis center. The big data analysis center will connect data sources corresponding to the related subsystems (either one data source or multi data sources), collect big data from the subsystems and analyze them, and submit the

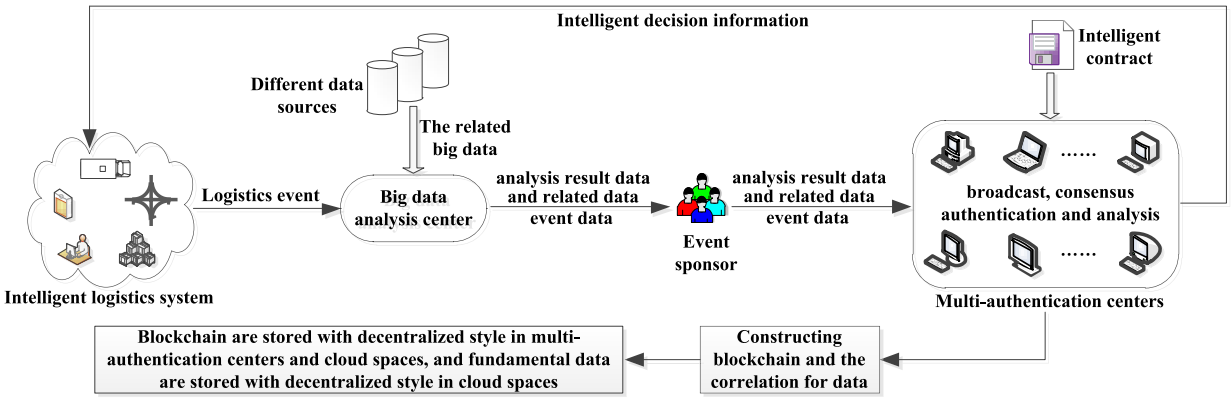

FIGURE 4. The operation principle of intelligent logistics system based on blockchain.

analysis result data and the abstract information of big data and data sources that corresponding to the analysis result data to the event sponsor of intelligent logistics system based on blockchain. Because of the relevance and consistency of the supporting data of the similar events in intelligent logistics system, the decision data of each event have higher importance to the decision of the subsequent similar events. Therefore, in the consensus analysis of the events in intelligent logistics system, the formed big data in decision support system have higher importance. The operation principle of intelligent logistics system based on blockchain is shown in Fig. 4.

The operation principle of intelligent logistics system based on blockchain can be described as:

a) The operation process of intelligent logistics system triggers logistics events (issued by specific entities, they can be business entities, can be distribution entities (intelligent transportation vehicles), can also be monitoring centers, etc.).
b) Logistics events transmit data requirement information to big data analysis centers. Big data analysis center connects related data sources according to the characteristics of events, collects data from related data sources and analyzes, and feedbacks the analysis result data and the abstract information of big data and data sources that corresponding to the analysis result data to event sponsor.
c) The event sponsor broadcasts the submitted data (analysis result data, the abstract information of big data and data sources that corresponding to the analysis result data) from the big data analysis center and the event data in ''multi-authentication centers'' (formed by government agencies, industry associations or logistics nodes, etc.) with the form of P2P.
d) ''Multi-authentication centers'' consensus authenticate the received data, confirm its authenticity, and initiate corresponding intelligent contract according to the event characteristics for consensus analysis and decision.
e) ''Multi-authentication centers'' issue intelligent decision instructions (existing in the form of decision result data) to intelligent logistics system. ''Multi-authentication centers'' construct the correlations between the related fundamental data (including the submitted data from big data analysis center, the event data, and the decision result data) and the corresponding blockchain, the other fundamental data in the same blockchain, the fundamental data in different blockchain, and the correlations are recorded in the blockchain. The blockchain are stored by ''multi-authentication centers'' and the appointed cloud storage spaces with decentralized style, and the fundamental data are stored by the appointed cloud storage spaces with decentralized style.

The generation principle and correlation of blockchain corresponding to different events in intelligent logistics system are shown in Fig. 5.

Because correlation are constructed among the data corresponding to some a blockchain and the data corresponding to different blockchain, so, for the different events in the same type of events, if the data used for event decision have great repeatability, we can construct the tag of data, the subsequent events can only store the tag of data in the process of storage, to avoid the waste of storage space caused by redundant storage of the same data, and to improve the efficiency of data retrieval. Because different ''multi-authentication centers'' have been established for different events of intelligent logistics system, so, different ''multi-authentication centers'' can also mutually supervise the authentication behaviors of the other ''multi-authentication centers'', that is, different ''multi-authentication centers'' can authenticate the authentication behaviors of the other ''multi-authentication centers'' to the related data, each blockchain is the main chain relative to itself, and is a side chain relative to the other blockchain, that further ensures the supervisability of the authentication behaviors of ''multi-authentication centers'', improve the working efficiency of ''multi-authentication centers'' and the transparency of authentication behaviors. The principle of mutual authentication and supervision of different ''multi-authentication centers'' is similar to the supervision of ''multi-authentication centers'' to the in-transit operation process of intelligent logistics system, so, this paper will not discuss in detail.

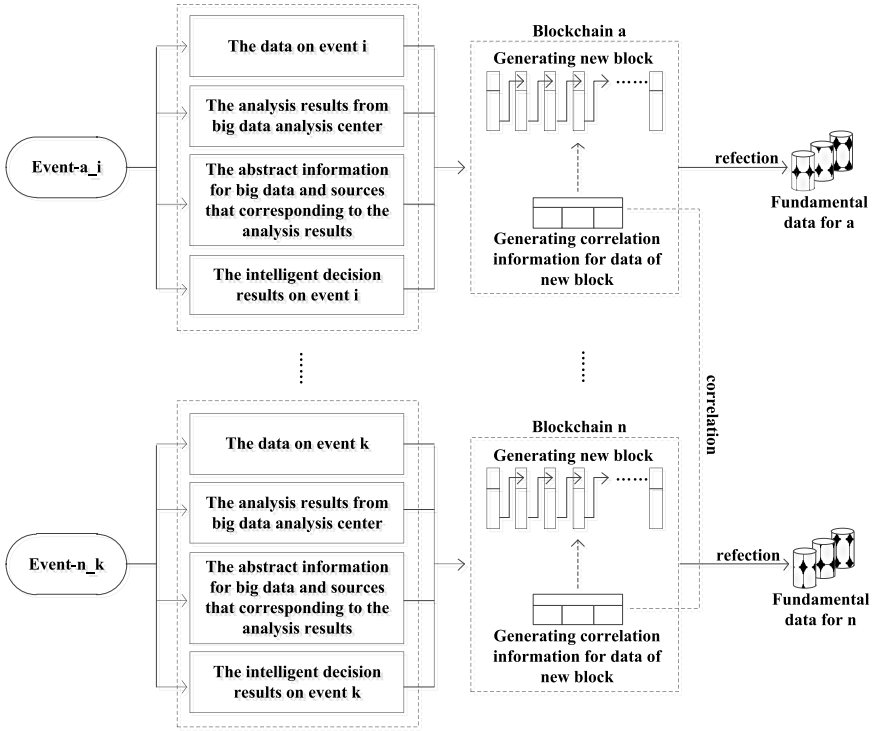

FIGURE 5. The generation principle and correlation of blockchain.

B. CONSENSUS AUTHENTICATION MECHANISM

The consensus authentication mechanism of intelligent logistics system based on blockchain is used to authenticate the authenticity of transmitted data of the system, initiate the corresponding intelligent contract according the concrete event, and form the decision of event through data analysis.

Because of the importance of drugs to the national development and people's livelihood, pharmaceutical logistics has achieved high concern from countries all over the world, and its modernization and information level is also high. Therefore, the intelligent logistics system for the pharmaceutical industry has come into being. Intelligent logistics system for pharmaceutical industry is responsible for order management, distribution decision, vehicle dispatch, traffic route selection, etc. of the process of logistics, and is also responsible for the supervision of the quality of drugs. Therefore, it is not enough to simply improve the level of intelligence of intelligent logistics system for pharmaceutical industry. Guaranteeing the authenticity, completeness, confidentiality of the related data of intelligent logistics system, and establishing a convenient and effective data retrieval system and data analysis system, is also the important content of realizing the intelligence of logistics system for the pharmaceutical industry. Therefore, this paper makes the distribution decision of pharmaceutical industry as an example to research the consensus authentication mechanism of intelligent logistics system based on blockchain. The consensus authentication subjects in the process of drug distribution decision come from the Food and Drug Administration, pharmaceutical factories, distribution centers, pharmaceutical companies, etc., because these institutions or organizations are volunteer to attend the consensus authentication on the basis of profit, so, in here, the incentive mechanism of authentication behaviors and accounting behaviors in the process of consensus authentication will not be considered.

Using *Data_order* to express the drug order data, using *Data_analysis* to express the suppliers' distribution capability data achieved from the analysis of big data analysis center, using *Data_abstract* to express the abstract information of big data and data sources that corresponding to *Data_analysis*, using *Data_authen* to express the authenticity authentication results, and using *Data_decision* to express the decision data of drug distribution. Using *authen_sub i* ($i = 1, 2, \cdots, n$) to express one of the consensus authentication subjects as 1-n. Using *intell_con j*() ($j = 1, 2, \cdots, m$) to express one of the intelligent contracts as 1-m. Using *distri_goods* to express distribution goods, using *distri_amount* to express distribution amount, using *distri_time* to express distribution time, using *distri_price* to express distribution price, and using *distri_plan* to express distribution plan.

1) THE CONSENSUS AUTHENTICATION ALGORITHM OF INTELLIGENT LOGISTICS SYSTEM

The consensus authentication algorithm of intelligent logistics system can be described as following:

Consensus Authentication Algorithm()

Input: *Data_order, Data_analysis, Data_abstract*
Output: *Data_authen* and *intell_con j*()

Algorithm:
For ($i = 1, i < n, i++$)
{*authen_sub i* authenticate *Data_order, Data_analysis, Data_abstract*}
// *any authen_sub i anthenticate the authenticity of Data_order, Data_analysis, Data_abstract*
If the *Data_authen* of any *authen_sub i* are *"true"* and *"coincident"*
Do case
Case "*order management*"
goto *intell_con* 1()
Case "*distribution decision*"
goto *intell_con* 2()
Case "*vehicle dispatch*"
goto *intell_con* 3()
.....
Case "*intelligent logistics process evaluation*"
goto *intell_con m*()
Otherwise
"the event is not a rational intelligent logistics system event"
Endcase
Else
goto *authen_error*()
Endif

intell_con 2()

Input: *Data_order, Data_analysis, Data_abstract*
Output: *Data_decision*

Algorithm:
For ($i = 1, i < n, i++$)
{*authen_sub i* does following:
compute *distri_goods*
compute *distri_amount*
compute *distri_time*
compute *distri_price*
make *distri_plan*
enable the *event* on *"vehicle dispatch"*
enable the *event* on *"traffic routes"*}
If the *Data_decision* of any *authen_sub i* are *"coincident"*
send the *Data_decision* to "*event enabled subject*"
constructed and stored blockchain by any *authen_sub i*
blockchain are stored in *cloud spaces* with distributed style
fundamental data are stored in *cloud spaces* with distributed style
Else
goto *authen_error*()
Endif

Authen_Error()

Input: *Data_order, Data_analysis, Data_abstract*
Output: *Data_authen* or *Data_decision*

Algorithm:
Enabling another "multi-authentication centers" to authenticate the authenticity or implement *intell_con j*()

2) THE INTELLIGENT CONTRACT ALGORITHM OF DISTRIBUTION DECISION OF INTELLIGENT LOGISTICS SYSTEM

The intelligent contract algorithm of distribution decision of intelligent logistics system can be described as following:

3) THE ERROR HANDLING ALGORITHM OF CONSENSUS AUTHENTICATION

The handling algorithm of the data not being true or the consensus authentication results not being consistent in the process of consensus authentication can be described as following:

For the consensus authentication process of events as order management, vehicle dispatch, traffic route selection, drug quality supervision, and intelligent logistics system evaluation for pharmaceutical industry, we can refer to the consensus authentication process of distribution decision of intelligent logistics system for pharmaceutical industry, this paper will not discuss more.

C. DATA STORAGE AND ACCESS MECHANISM

Because of the great capacity of the operation related data of intelligent logistics system, this paper proposes that in the intelligent logistics system based on blockchain, the fundamental data (event data, analysis result data from big data analysis center, the abstract information of big data and data sources that corresponding to the analysis result data, decision result data produced by "multi-authentication centers" operating intelligent contract) of system operation are stored respectively with blockchain. In view of the confidentiality requirement of the operation data and the related big data that support decision of intelligent logistics system, this paper proposes by "multi-authentication subjects" ("multi-authentication subjects" is corresponding to concrete type of event.) storing the blockchain body that corresponding to the fundamental data in the event operation of system, while the operation fundamental data of the system are stored with decentralized style in the cloud spaces that are appointed by intelligent logistics system. The blockchain body is also stored with decentralized style in the cloud spaces that are appointed by intelligent logistics system, and is constructed mapping relationships with the fundamental data. In order to further improve the confidentiality of the fundamental data, this paper divides cloud space into "front cloud space" and "back-end cloud space" ("front cloud space" and "back-end cloud space" are just image terms, which have no practical significance). The newly produced fundamental data are stored in "front cloud space", when the data

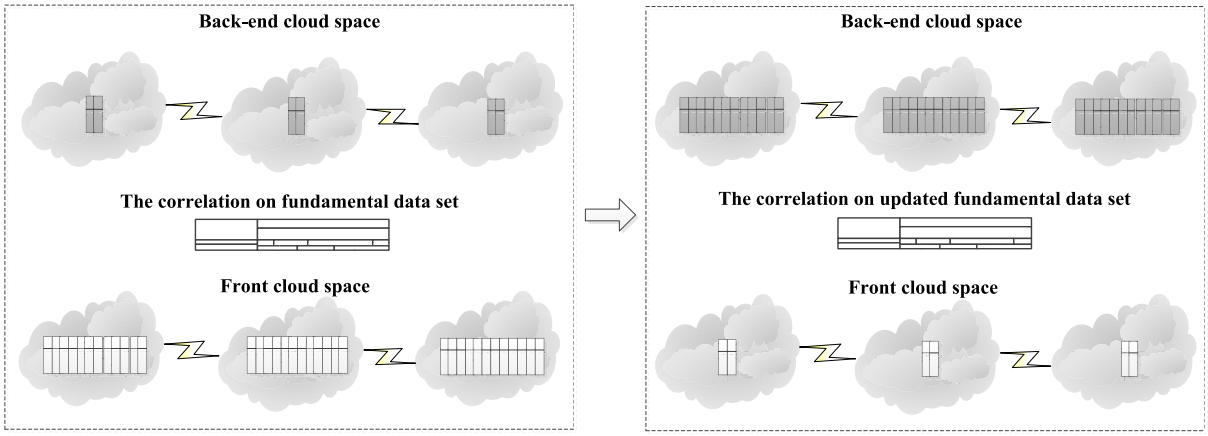

FIGURE 6. The storage mechanism of fundamental data of intelligent logistics system based on blockchain.

capacity of ''front cloud space'' reaches to a certain extent (e.g. M), the precursor data(earlier producing data) with a certain capacity (e.g. N) in the fundamental data of ''front cloud space'' will automatically move from ''front cloud space'' to ''back-end cloud space'', and the fundamental data that moved to ''back-end cloud space'' will maintain the mapping relationships with the blockchain, and maintain the correlations with the fundamental data still in ''front cloud space''. The correlations need be constructed by adding connection records and abstract illustrations between the fundamental data in ''front cloud space'' and the fundamental data in ''back-end cloud space'' according to the actual situation. The data structure of moved fundamental data in ''back-end cloud space'' can be the original structure or be reorganized into a new structure. The storage mechanism of fundamental data of intelligent logistics system based on blockchain is shown in Fig. 6.

In Fig. 6, the fundamental data of ''front cloud space'' and the fundamental data of ''back-end cloud space'' are respectively stored with decentralized style in different cloud spaces according to the requirements. The fundamental data stored in ''back-end cloud space'' will be accessed by visitors under authorization. For the access process of the visitors, we can also construct the corresponding blockchain authentication system. By establishing ''multi-authentication centers'' to consensus authenticate the identity and access privileges of the visitor, to realize the supervision to the visitor. The blockchain system will record the identity data and access behavior data of the visitor, for avoiding the illegal access and use of the visitor to the data. The structure and operation principle of blockchain authentication system on data access of ''back-end cloud space'' is similar to the intelligent logistics blockchain system, so, this paper will not discuss in detail.

IV. RESULTS

The main results of this research can be generalized as following:

1) THE OPERATION PRINCIPLE OF INTELLIGENT LOGISTICS SYSTEM BASED ON BLOCKCHAIN IS CONSTRUCTED

The research provided a total framework of blockchain technology applying in intelligent logistics system, and resolved the authenticity, traceability, and security of data being operated in intelligent logistics system.

2) CONSENSUS AUTHENTICATION MECHANISM IS CONSTRUCTED

The research provided the methods of group authentication, supervision, and decision-making for the operation of data and intelligent contract in intelligent logistics system.

3) THE DATA STORAGE MECHANISM AND ACCESS MECHANISM ARE CONSTRUCTED

The research ensured the confidentiality, storage security and access security of the fundamental data that corresponding to the blockchain.

4) THE DECISION DEPENDENT DATA ARE EXPANDED TO THE RELATED BIG DATA OF INTELLIGENT LOGISTICS SYSTEM

The research improved the scientific, rationality, and intelligence of the decision of intelligent logistics system.

5) DIFFERENT BLOCKCHAIN SYSTEMS ARE CONSTRUCTED CORRESPONDING TO DIFFERENT EVENTS

The research made it easy to operate a unified intelligent contract in the blockchain for the same events, and to construct different ''multi-authentication center'' for different events.

6) THE CORRELATIONS BETWEEN DATA ARE CONSTRUCTED AND RECORDED

The research is conducive to improve the efficiency of data retrieval and realize the traceability of data operation process.

Based on the classical blockchain technology, and aimed at the characteristics of intelligent logistics system, this paper constructed a specific architecture and operation mechanisms. The function structure and implementation principle

of the proposed intelligent logistics system based on blockchain are universal, and do not exceed the structure characteristics of information system and the technology scopes of blockchain, for specific application environment, blockchain system can be adjusted according to application requirements, so, we will not further to test or prove the architecture or operation mechanisms. This paper has taken the logistics of pharmaceutical industry as an example to design the algorithms, so other case analysis will no longer be carried out.

V. CONCLUSION

Big data are the basis of supporting the operation of intelligent logistics system, and are also the inevitable product of the operation of intelligent logistics system. However, due to the diversity and openness of data sources of big data, big data faces the risks as data being destroyed, changed, and privacy leaked, etc. in the process of transmission and storage, these are also at present the important problems that encountered by big data in the process of application. Although the academic circles have done a lot of researches on the security and privacy risks of big data in the operation process, but the origin of problems still not be restrained, and once the problem arises, the trace afterwards is difficult.

Applying blockchain technology can realize the non-repudiation proof and traceability of business activities. From the technological perspective, blockchain can solve the security of data transmission and data storage, realize the traceability of the process of producing, operation, and storage of data, and realize the group supervision of the operation of business data and generate decision. Although the classic blockchain technology has obvious limitations in the respects of data confidence and storage redundancy, but because of blockchain structure's openness and functional adjustability for concrete application environments, blockchain's strong vitality and application value have been uniformly accepted by experts in various fields, and blockchain has achieved rapid development.

At present, the application research of blockchain in traffic, transportation, and logistics is in the primary stage, and the corresponding research results have not formed the guidance for building blockchain system in the fields of intelligent traffic, intelligent transportation, and intelligent logistics. Basing on this, this paper proposes an operational framework of intelligent logistics system based on blockchain, construct a big data analysis center to collect, analyze the related big data, and the analysis result data and the abstract information of big data and data sources that corresponding to the analysis result data will be broadcast, recorded, and stored in blockchain system.

Because of the characteristics of the blockchain itself, the blockchain will face the following problems when it is applied to an intelligent logistics system:

1) The problem of the system boundary definition. Since intelligent logistics system is an open environment, how to define the scope of the blockchain system application, how to define the scope of the related big data and the transmission method of different types of data in blockchain, and how to define and select blockchain authentication subjects will face many problems as business requirements, data handling, and management institution support, etc.
2) The problem of the system application. Although many industries have developed prototype blockchain systems, and the scalability of the corresponding prototype system is also very strong, but the blockchain itself is a combination of many aspects of information security technology, and intelligent logistics system has the characteristics of pervasive, participants spanning a wide range from technical abilities to scale, so, the constructed intelligent logistics system based on blockchain need larger openness and lower access threshold. Otherwise, because the blockchain is a developing technology system over the recent years, the real life applications are rare, and most people do not have basic knowledge of blockchain. Therefore, significant time is still required for the managers and users to accept intelligent logistics system based on blockchain.
3) Integration problems with other systems. Since an intelligent logistics system based on blockchain needs induce the analysis result data of the external big data and the related data, and the connection between different systems, data collecting and data analysis, and the abstract information recording on the related big data and data sources that corresponding to the analysis result data are fulfilled by big data analysis center, so, there is a high requirement to big data analysis center. Therefore, the requirements are also very high for meeting the construction of corresponding big data analysis center. In addition, because the intelligent logistics system based on blockchain is constituted by multi blockchain systems, the realization of the different blockchain systems' links, mutual access, and supervision with each other will also present more and higher requirements for the real environment and the software and hardware of system.

The research's most distinctive innovations are constructing correlations between fundamental data and recording the correlations in blockchain system, and introducing the analysis results of related big data for intelligent logistics system into blockchain system and recording them. The research's most distinctive limitation is lacking of demonstrating to the rationality of the operation mechanisms.

This paper has proposed the operation mechanisms for intelligent logistics system based on blockchain, the research still has significant work prior to a system's construction and final application. In the future, we will further research the blockchain system's application and development in the field of intelligent logistics, promote the research content implementation of this paper, at the same time, we will also research the performance evaluation of intelligent logistics system based on blockchain, for providing the application

value of blockchain technology. The research has provided thoughts for the application combination of big data and blockchain system, and proposed a complete architecture for blockchain applying in intelligent logistics system. The research results have the same guiding significance for other similar researches, and will promote the progress of application research of blockchain technology in specific fields.

REFERENCES

[1] Y. Feng, P. Zhou, J. Xu, S. Ji, and D. Wu, "Video big data retrieval over media cloud: A context-aware online learning approach," *IEEE Trans. Multimedia*, vol. 21, no. 7, pp. 1762–1777, Jul. 2019.

[2] S. S. Yao, "Research on the key technology of big audio retrieval," Ph.D. dissertation, Taiyuan Univ. Technol., Taiyuan, China, 2018.

[3] X. Wu and S. Ji, "Comparative study on map reduce and spark for big data analytics," *J. Softw.*, vol. 29, no. 6, pp. 1770–1791, 2018.

[4] H. S. Sim, "Big data analysis methodology for smart manufacturing systems," *Int. J. Precis. Eng. Manuf.*, vol. 20, no. 6, pp. 973–982, 2019.

[5] W. L. Wang, Z. J. Zhang, N. Gao, and Y. W. Zhao, "Progress of big data analytics methods based on artificial intelligence technology," *Comput. Integr. Manuf. Syst.*, vol. 25, no. 3, pp. 529–547, 2019.

[6] D. Lv, S. Zhu, and R. Liu, "Research on big data security storage based on compressed sensing," *IEEE Access*, vol. 7, pp. 3810–3825, 2019.

[7] I. S. Rubinstein, "Big data: The end of privacy or a new beginning?" *Int. Data Privacy Law*, vol. 3, no. 2, pp. 74–87, 2013.

[8] D. G. Feng, M. Zhang, and H. Li, "Big data security and privacy protection," *Chin. J. Comput.*, vol. 37, no. 1, pp. 246–254, 2014.

[9] X. S. Chen, L. Yang, and Y. G. Luo, "Big data security technology," *Adv. Eng. Sci.*, vol. 49, no. 5, pp. 1–12, 2017.

[10] D. Kavanagh and G. Miscione, "Bitcoin and the blockchain: A coup d'état in digital heterotopia?" in *Proc. 9th Int. Conf. Crit. Manage. Stud., Alternative*, Leicester, U.K., 2015, pp. 1–28.

[11] J. Zhang, *Blockchain: Define the Future Finance and Economic New Pattern*. Beijing, China: Machinery Industry Press, 2016.

[12] S. Nakamoto. (2016). *Bitcoin: A Peer-to-Peer Electronic Cash System*. [Online]. Available: https://bitcoin.org/bitcoin.pdf

[13] V. Buterin. (2016). *Ethereum White Paper*. [Online]. Available: https://github.com/ethereum/wiki/wiki/White-Paper

[14] G. Wood. (2016). *Ethereum Yellow Paper*. [Online]. Available: http://gavwood.com/paper.pdf

[15] S. S. Feng, "Blockchain: The possibility of credit endorsement big data era," in *Proc. CFO World*, Mar. 2016, pp. 14–17.

[16] B. Goertzel, T. Goertzel, and Z. Goertzel, "The global brain and the emerging economy of abundance: Mutualism, open collaboration, exchange networks and the automated commons," *Technol. Forecasting Social Change*, vol. 114, pp. 65–73, Jan. 2017.

[17] A. Hughes, A. Park, J. Kietzmann, and C. Archer-Brown, "Beyond bitcoin: What blockchain and distributed ledger technologies mean for firms," *Bus. Horizons*, vol. 62, no. 3, pp. 273–281, 2019.

[18] F. Gao, "Data encryption algorithm for E-commerce platform based on blockchain technology," *Discrete Continuous Dyn. Syst.-Ser. S*, vol. 12, nos. 4–5, pp. 1457–1470, 2019.

[19] Y. Fu and J. Zhu, "Big production enterprise supply chain endogenous risk management based on blockchain," *IEEE Access*, vol. 7, pp. 15310–15319, 2019.

[20] J.-H. Huh and S.-K. Kim, "The blockchain consensus algorithm for viable management of new and renewable energies," *Sustainability*, vol. 11, no. 11, p. 3184, 2019. doi: 10.3390/su11113184.

[21] Y. Fu, J. Zhu, and S. Gao, "CPS information security risk evaluation based on blockchain and big data," *Tehnički Vjesnik*, vol. 25, no. 6, pp. 1843–1850, 2018.

[22] Y. M. Yu, T. W. Chen, Z. T. Duan, and K. Zhao, "Research on the sharing model of government information resources based on blockchain," in *Proc. e-Government*, Apr. 2019, pp. 58–67.

[23] D. Han, C. Z. H. Zhang, W. Q. Sun, W. Zhang, W. W. Yang, and M. Xiao, "Framework design of smart distribution trading platform based on blockchain technology," *Autom. Electr. Power Syst.*, vol. 43, no. 7, pp. 89–96, 2019.

[24] J. H. Ziegeldorf, R. Matzutt, M. Henze, F. Grossmann, and K. Wehrle, "Secure and anonymous decentralized bitcoin mixing," *Future Gener. Comput. Syst.*, vol. 80, pp. 448–466, Mar. 2018.

[25] C. Fromknecht, D. Velicanu, and S. Yakoubov. (2016). *A Decentralized Public Key Infrastructure With Identity Retention*. [Online]. Available: https://eprint.iacr.org/2014/803.pdf

[26] C. Fromknecht, D. Velicanu, and S. Yakoubov, "CertCoin: A namecoin based decentralized authentication system," Class Project, Massachusetts Inst. Technol., Cambridge, MA, USA. Tech. Rep. 6.857, 2014.

[27] R. Morselli, B. Bhattacharjee, and J. Katz. (2016). *KeyChains: A Decentralized Public-Key Infrastructure*. [Online]. Available: https://www.researchgate.net/publication/228714967_Keychains_A_decentralized_public-key_infrastructure

[28] T. T. Kuo, C. N. Hsu, and L. Ohno-Machado. (2016). *ModelChain: Decentralized Privacy-Preserving Healthcare Predictive Modeling Framework on Private Blockchain Networks*. [Online]. Available: https://www.healthit.gov/sites/default/files/10-30-ucsd-dbmi-onc-blockchain-challenge.pdf

[29] Y. S. Tian, G. H. Zhao, and L. Y. Shen, "Blockchain transportation: Taking freight logistics and the market governance as the example," *China Bus. Market*, vol. 32, no. 2, pp. 50–56, 2018.

[30] Y.-T. Yang, L.-D. Chou, C.-W. Tseng, F.-H. Tseng, and C.-C. Liu, "Blockchain-based traffic event validation and trust verification for VANETs," *IEEE Access*, vol. 7, pp. 30868–30877, 2019.

[31] E. Tijan, S. Aksentijević, K. Ivanić, and M. Jardas, "Blockchain technology implementation in logistics," *Sustainability*, vol. 11, no. 4, p. 1185, 2019. doi: 10.3390/su11041185.

[32] P. X. Zhao, W. H. Luo, and X. Han, "Time-dependent and bi-objective vehicle routing problem with time windows," *Adv. Prod. Eng. Manage.*, vol. 14, no. 2, pp. 201–212, Jun. 2019.

[33] M. Tang, D. Gong, S. Liu, and X. Lu, "Finding key factors for electric vehicle charging station location: A simulation and ANOVA approach," *Int. J. Simul. Model.*, vol. 16, no. 3, pp. 541–554, 2017.

[34] N. Gjeldum, M. Crnjac, and B. Bilić, "Simulation of bullwhip effect in a supply chain for lean learning factory purposes," *Int. J. Simul. Model.*, vol. 16, no. 4, pp. 576–589, 2017.

[35] S. Supsomboon and T. Varodhomwathana, "Robot and plant simulation for automotive part production process design: A case study," *Int. J. Simul. Model.*, vol. 16, no. 4, pp. 617–629, 2017.

YONGGUI FU was born in Shanxi, China, in 1976. He received the B.S. and M.S. degrees from the Shanxi University of Finance and Economics, Taiyuan, China, in 1998 and 2007, respectively, and the Ph.D. degree from the Central University of Finance and Economics, Beijing, China, in 2018.

He is currently an Associate Professor with the Shanxi University of Finance and Economics. His research interests include big data and blockchain.

JIANMING ZHU was born in Shanxi, China, in 1965. He received the M.S. degree in computer application from the Taiyuan University of Technology, Taiyuan, China, in 1998, and the Ph.D. degree in computer application technology from Xidian University, Xi'an, China, in 2004.

He is currently a Professor, a Doctoral Supervisor, and the Dean of the Central University of Finance and Economics, Beijing, China. His research interests include CPS, information security, and blockchain.