Blockchain-Based Knowledge Automation for CPSS-Oriented Parallel Management

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***Abstract*— Traditional organization management typically follows a top–down pyramid structure, which is widely believed to have many problems in releasing innovation potentials. In the new era of intelligent technologies, knowledge automation is required to meet the urgent demand for rapid acquisition and application of knowledge. With the rapidly deepened integration of the real world and the virtual society, cyber–physical–social system (CPSS)-oriented parallel management proves to be an effective and efficient way in solving these problems. In this article, we utilize blockchain technology and smart contracts in knowledge automation and investigate blockchain-based knowledge automation, which can be used for CPSS-oriented parallel management. We also propose a management framework based on the smart contract and discuss a case study.**

***Index Terms*— Blockchain, cyber–physical–social systems (CPSSs), knowledge automation, parallel management, smart contract.**

I. Introduction

With the development of information and network technologies, our society has gradually evolved from the industrial era into the new era of knowledge economy. Just as the industrial society that realizes the industrial automation, the knowledge society is expected to require the realization of knowledge automation to meet the urgent demand for the rapid acquisition and application of knowledge [4], [12].

From the point of view of automation, compared with mechanical automation or electrical and electronic automation of physical processes, the essence of knowledge automation is the deep development and intelligence mining of virtual space, and it is the natural extension and improvement of information automation, and the inevitable requirement of human participated in automation. It is also the foundation of the transformation from the automatic control of the physical world to the intelligent management of our society. Such transformation can be realized using automation in virtual space, and the core is knowledge automation. In knowledge automation, the modeling and analysis of human and social behaviors are important aspects, which greatly rely on Merton's law. In the abovementioned processes, technologies, such as machine learning and human–computer interactions, should be integrated to affect people's consciousness and behavior patterns, so as to achieve the desired control or management goals.

In the era of big data, how to realize the dynamic closed-loop feedback and real-time interaction among big data, knowledge, and human has become the main challenge of knowledge automation. Knowledge automation will change the way of the acquisition, analysis, impact and generation of knowledge, as well as the way of decision-making, evaluation, and implementation. It can realize the integration and transformation from data to information and further to knowledge and wisdom, so as to lead the change of future work, organizational structure, economic growth, and productivity.

The aim of knowledge automation is to move from physical world-oriented industrial automation to data and cyberspace-oriented knowledge automation [1]. Knowledge automation can expand human intelligence through machines, and it is the only way from industrialization to intelligence. The key to knowledge automation is how to integrate information and intelligence with tasks and decision-making seamlessly, accurately, timely, and online, so as to automatically complete various knowledge functions and knowledge services.

Therefore, in this article, we propose a knowledge automation method based on blockchain technology [17]–[19] and cyber–physical–social systems (CPSSs) [33], which can be applied to the production planning, management, and optimization process of industry, so as to realize the smart interaction among human, machine, and objects. This method is an attempt to move from data information automation to knowledge automation and intelligent management under the background of enterprise information processes. Cyberspace is affecting our life and work with great impact, and the virtual cyberspace has become a real part of our life. Facing virtual space, developing data and intellectual resources is an inevitable trend of knowledge society in the future. Knowledge automation and related intelligent technology are the cornerstone of the transformation and upgrading of China's industry, which is of great significance to China's social and economic development.

Manuscript received June 30, 2020; revised August 12, 2020 and September 2, 2020; accepted September 6, 2020. This work was supported in part by the National Key Research and Development Program of China under Grant 2018AAA0101401 and in part by the National Natural Science Foundation of China under Grant 71702182 and Grant 61533019. *(Corresponding author: Rui Qin.)*

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Digital Object Identifier 10.1109/TCSS.2020.3023046

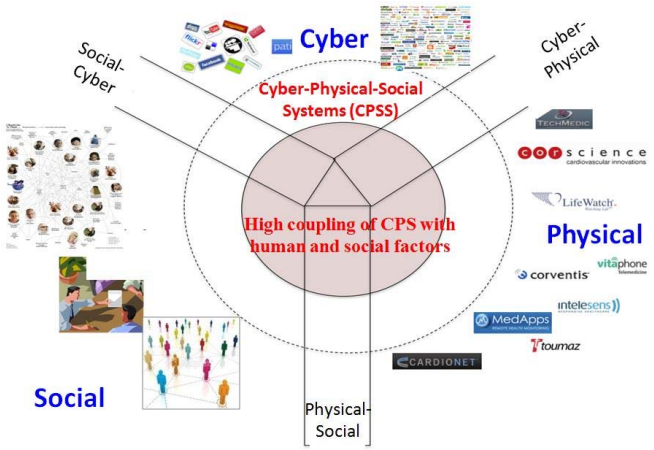

Fig. 1. Cyber-Physical-Social Systems.

The main contribution of this article includes the following three aspects. First, we propose a framework for parallel management. Second, we propose a blockchain-based knowledge automation method for parallel management. Third, we use the decentralized autonomous organization (DAO) to realize the parallel management real-timely.

The rest of this article is arranged as follows. In Section II, we introduce CPSS as well as the related problems and requirements for management. In Section III, we propose the concept and framework of parallel management. In Section IV, we proposed a blockchain-based knowledge automation approach for parallel management. In Section V, we introduce how to realize the real-time management based on DAO. In Section VI, we give a case study. Section VII concludes this article.

II. Cyber–Physical–Social Systems

A. CPSS-Based Problems and Requirements for Management

The concept of CPSS is proposed based on cyber–physical systems (CPSs) (as shown in Fig. 1). It integrates the artificial system of social information and virtual space into CPS and extends the research scope to the social network systems [23]. It includes the ubiquitous embedded environment perception, the dynamic analysis of human's organizational behaviors, network communication, and network control, which make the physical system have the functions of computing, communication, precise control, remote cooperation, and autonomy. It pays attention to the close combination and coordination of human brain, computing, and physical resources. It will be applied in many fields, such as intelligent enterprise, intelligent transportation, smart home, and intelligent medical treatment. It realizes the organic combination of personnel organization and physical entity system through intelligent human–computer interaction, which makes individuals and organizations in controlling physical entity in a reliable, real-time, safe, and cooperative way through network space.

In recent years, the trend of the integration of the real world and the virtual society is becoming more and more obvious, which brings a deep coupling and strong feedback

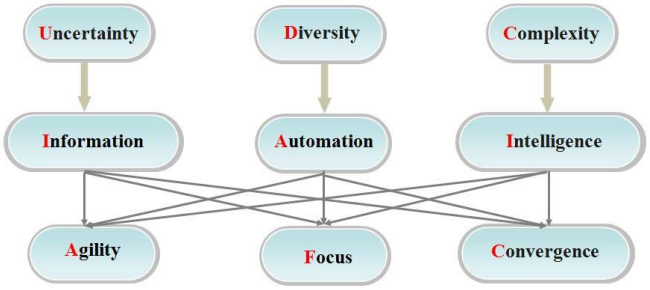

Fig. 2. Objective of management: from UDC to AFC.

in physical, psychological, and cyberspace to modern society. It is an important challenge for modern management to quickly acquire knowledge from the Internet and massive data to serve humans and help humans deal with various, uncertain, and complex tasks timely, in order to realize the dynamic closed-loop feedback and real-time interaction among big data, knowledge, and human. To a certain extent, the change of management is to make use of the unlimited data and information resources in the network world, break through the constraints of the limited resources and the limitations of the space–time in the physical world, and utilize the virtual–reality parallel interaction technology to truly incorporate "human" into the management ecosystem [22]. At present, management still depends on human's experience, and it is difficult to fully consider the impact of human and social factors, which make management problems face great uncertainty, diversity, and complexity (UDC) [24]. As such, with technologies of information, automation, and intelligence, the CPS-based management will be replaced by the CPSS-based parallel management, which can deal with the management issues of UDC with capacity of agility, focus, and convergence (AFC), as shown in Fig. 2.

B. Way to CPSS-Based Management: Blockchain, Parallel Management, and Knowledge Automation

Blockchain, parallel management, and knowledge automation are important theories and technologies to solve CPSS-based management problems. They can provide a set of effective decentralized data structure, interaction mechanisms, and management models for the distributed social system and parallel social management and provide solid data and credit foundation for the realization of parallel social management.

III. Parallel Management: Concept and Framework

A. Parallel Systems, ACP Approach, and Parallel Management

In this section, we introduce the concepts of parallel systems, artificial societies, computational experiments and parallel execution (ACP) approach, and parallel management.

The concept of parallel systems was proposed by Fei-Yue [21], and it refers to a system composed of a natural real system and one or more virtual or ideal artificial systems. In parallel systems, there are two important parts called the

artificial system and the actual system. In short, an artificial system is a software-defined system, which is not only the digital "simulation" of the actual system but also an alternative version (or possible situations) of the actual system, so as to realize online, dynamic, and active control and management of the actual system, and provide efficient, reliable and applicable scientific decision-making for the actual complex system management.

The ACP approach is the only systematic and complete research framework in the field of parallel social management so far and is the logical extension and innovation of complexity science in the new era of parallel social environment. By utilizing the agent-based artificial system, it can well describe the complex system and solve the problems that can hardly be analytically modeled in real complex systems. It uses the computer as the laboratory and makes computational experiments in the artificial system, in the cases that it is difficult or even impossible to make experiments or repeat experiments in real systems. With the parallel execution of real systems and artificial systems, we can realize the management and control of complex systems.

Parallel management was proposed based on the theory of parallel system and CPSS. It uses the ACP approach to carry out closed-loop management of complex systems, and it is an effective method to realize management and control, as well as the qualitative and quantitative analysis of complex systems with both social and engineering complexities.

B. Comparisons of Parallel Management and Digital Twins

Parallel management and digital twins are similar methodologies, and digital twins is a concept in the CPS in Industries 4.0, whereas parallel management is a concept of CPSS [28]. Digital twins is a key technology, and it aims to map physical systems to digital models in the information space. It analyzes and models physical entity data by using sensors arranged in each part of the systems and reflects the full-life process in different real scenes. It mainly includes a physical entity in the physical space, a virtual entity in the artificial space, and connection data and information between them.

The key idea of digital twins is to build the artificial counterparts to the physical entities and then optimize and control the complex virtual–real systems through experiments in the artificial systems. Besides the abovementioned key idea, parallel management considers the uncertain, diversified, and complex issues in social systems and thus can be regarded as a research paradigm of "social digital twins," which is an effective way to realize the CPSS-based "Industries 5.0."

C. Research Framework of Parallel Management

By combining the parallel system and ACP approach, parallel management aims to build an artificial socioeconomic system running in parallel with the actual social-economic system. Through the interactions of the two systems, it can realize the management and control of the actual system, the experimentation and evaluation of relevant behaviors and decisions, and the learning and training of relevant personnel and systems, as shown in Fig. 3. The main purpose of parallel management is to compare and analyze the behavior between the actual system and the artificial system, complete the "reference" and "prediction" of the future situation, and adjust the management and control methods accordingly, so as to achieve effective solutions and the purpose of learning and training [24].

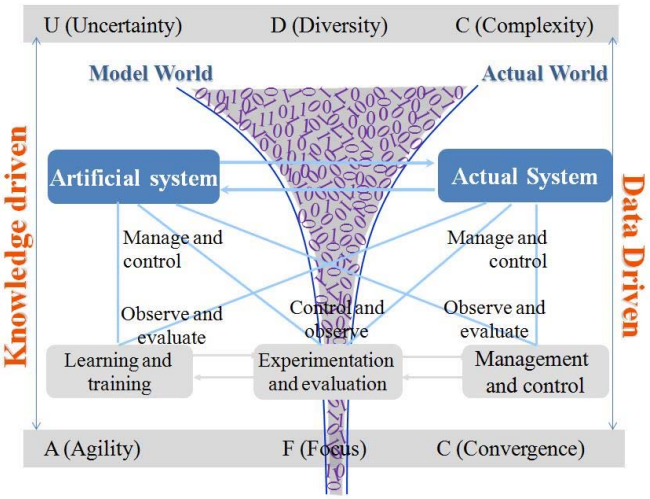

Fig. 3. Research framework of parallel management.

1) Experimentation and Evaluation: In this process, computational experiments are conducted in the artificial socioeconomic system to analyze and understand the behavior and response of different socioeconomic systems and evaluate the effect of different solutions as the basis for selecting and supporting management and control decisions.
2) Learning and Training: In this process, the artificial socioeconomic system is mainly used as the center for learning and training of a complex system. Through the proper combination of actual and artificial systems, the relevant personnel who manages and controls the actual complex socioeconomic system can quickly grasp the various conditions of the system and corresponding actions.
3) Management and Control: In this process, the artificial socioeconomic system attempts to simulate the actual socioeconomic system as much as possible and estimate the behavior in the actual system, so as to provide a basis for finding effective solutions to the actual system or improving the current scheme. Moreover, by observing the difference between the evaluation status of the actual system and the artificial system, error feedback signals are generated, and the evaluation methods or parameters of the artificial system are modified to reduce the differences between the two systems. Then, a new round of optimization and evaluation of the two systems starts.

IV. Blockchain-Based Knowledge Automation

A. Big Data-Based Knowledge Automation

Big data plays an important role in the CPSS-based parallel social management [25]. In the conventional centralized social

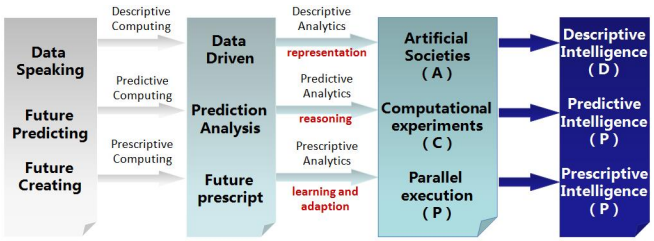

Fig. 4. Big data-based knowledge automation.

system, big data is usually possessed by a few organizations or individuals, such as the governments and large enterprises, and the impartiality, authority, and even security might not be guaranteed. With the blockchain technology, these data can be stored through highly redundant distributed nodes and can be accessed and applied by anyone in the blockchain system, which can well eliminate the centralization of data. From the perspective of credit basis, due to the high engineering complexity and social complexity, the central social system inevitably has the characteristics of "Merton system," namely, UDC. The central organizations and rule makers in such social system may have dishonest behaviors to increase individual interests. The blockchain technology helps to realize the software-defined social system, and its basic idea is to eliminate the central organizations and deploy and solidify the unpredictable behaviors in the blockchain data in advance in the form of the procedural code of the smart contract [3], [5], which cannot be forged and tampered with after the event. It can execute automatically, and thus, the "Merton" social system can be transformed into a "Newton" social system that can be fully observed, actively controlled, and accurately predicted [24], as shown in Fig. 4.

B. Blockchain Technology: An Overview

Blockchain technology was first proposed by Nakamoto [11]. In a narrow sense, blockchain is a kind of specific data structure, which links data blocks to a chain according to their generated time stamp. It is a nontamperable and nonforgeable decentralized shared ledger guaranteed by cryptography, and it can safely store simple, sequential data that can be verified within the system. In a broad sense, blockchain technology is a new decentralized infrastructure and distributed computing paradigm, which can verify and store data with encrypted block structure, generate and update data with a distributed consensus algorithm, and program and manipulate data with automated script code (e.g., smart contract) [13]–[15].

The characteristics of blockchain include decentralization, sequential data, collective maintenance, programmability, security, and trustworthiness [6], [31].

First, decentralization is one of the most important characteristics of blockchain technology. In the blockchain system, the verification, accounting, storage, maintenance, and transmission of data are based on the distributed system structure. It uses the mathematical method instead of the central organization to establish the trust between the distributed nodes, so as to form a decentralized and trustworthy distributed system. Second, blockchain uses a chain structure with time stamp to store data, which adds a time dimension to big data, and thus has stronger verifiability and traceability.

Third, with the help of economic incentive mechanisms, the blockchain system can ensure that all nodes in the distributed system can participate in the verification processes of the blocks and add new blocks to the blockchain through consensus algorithms.

Fourth, blockchain technology can provide a flexible script code system for users to create advanced smart contracts, currencies, or other decentralized applications. For example, Ethereum platform provides Turing complete script language for users to build any precisely defined smart contracts or transaction types.

Fifth, blockchain technology encrypts the data by using the asymmetric cryptography principle and thus has higher security. It can resist external attacks and ensure that the data in the blockchain cannot be tampered with and forged by consensus algorithms such as the proof-of-work (PoW) of each node in the distributed system.

C. Blockchain-Based Knowledge Automation

So far, blockchain has been successfully applied in many fields, such as data sharing, data authentication and anticounterfeiting, data traceability, and data security and privacy protection, which can help realize blockchain-based knowledge automation [32].

1) Data Sharing: With the development of information technology, the value of data is recognized by more and more organizations and individuals and has become the core assets and competitiveness of enterprises. At present, a large amount of data in various fields has been accumulated in enterprises and organizations. However, due to the differences in information systems among different enterprises and the restrictions of privacy protection regulations, these data cannot be shared by other enterprises or organizations in the industries, even among departments in the same enterprise. Blockchain technology can provide an effective way to solve the abovementioned problems. In blockchain, especially in the public chain, any node can read and write the data in the blockchain; as such, a trustless system is built with a distributed ledger. Each organization or individual in the blockchain does not have to trust each other, but they can reach a consensus on the final state of data stored in the blockchain system. With permission sharing, blockchain allows each participant to act as a data provider, a verifier, and a user to jointly maintain the security and effectiveness of blockchain data.

2) Data Authentication and Anticounterfeiting: In the digital era, electronic contracts are gradually replacing conventional paper contracts. As such, how to ensure the authenticity, objectivity, and nontamperability of the electronic contracts signed by multiple enterprises has become an important issue for enterprises. Due to the openness, transparency, and nontamperability of blockchain technology, blockchain can provide an effective solution to the abovementioned issue, and the electronic contract data stored in the blockchain cannot be

tampered with. Furthermore, by combining blockchain technology with judicial institutions, we can carry out synchronous authentication, which can transform ordinary electronic data to credible electronic evidence and realize data authentication, so as to meet the requirements of legal, authenticity, and associativity of electronic data in judicial practice. As such, with blockchain technology, the credibility of electronic data forensic in judicial activities can be enhanced greatly.

3) Data Traceability: Blockchain is a distributed public ledger with the characteristics of openness, transparency, and nontampering, and it has been widely used in commodity traceability. When combining blockchain technology with the Internet of Things (IoT), the traceability of goods can be realized. As such, any link from the source to the end can be traced back, including information collection records, raw material source traceability, production process, processing links, storage information, inspection batch, logistics turnover, the third-party quality inspection, customs entry and exit, and anticounterfeiting authentication. No matter whether the commodity traceability is in the form of public chain or alliance chain, it is open and transparent, and all users in the blockchain can record and view the information. As such, it can effectively solve the difficulties of coordination and information opacity in traditional commodity traceability since every department can enter and update their own certification on the chain and synchronize to bookkeepers in all chains. Another major feature of blockchain traceability is its uniqueness. Each record has a time stamp and cannot be tampered with. It can not only prevent individuals from doing evil but also prevent the third-party organizations from colluding with businesses to fake data.

4) Data Security and Privacy Protection: In accurate and personalized services, personal data are often necessary, which may contain a large number of sensitive information, such as income, identity, interest, and location. The sharing, collection, publishing, analysis, and utilization of these data will directly or indirectly disclose the users' privacy. Blockchain technology can provide an effective solution to the problem of user data security and privacy protection. Transaction data on the blockchain mainly include much information, such as transaction addresses, amounts, and transaction time, which are open, transparent, and viewable. However, the identity of the owner corresponding to the transaction address is anonymous. As such, with blockchain encryption technology, the user identity and user data can be separated by an encryption algorithm. When using these data for research and analysis, it can protect the users' privacy since the corresponding user name, phone, or registered mailbox cannot be obtained through hash operations. In addition, since the collected user data are stored in an encrypted and distributed way, the private key must be provided to access the data. As such, it can reduce the risk of data leakage.

D. Blockchain-Based Robotic Process Automation

With the rise of human resource cost, the rapid development of information technology, and the explosive growth of data volume, the operating cost of enterprises is increasing. In addition, with the diversification and complexity of the business operation of the enterprises, business processes become more and more complex, and information islands exist everywhere in the enterprise, which makes it difficult to improve the work efficiency of the employees. Therefore, how to reduce the human cost, improve the automation degree of business process and the work efficiency of employees, and promote the digital transformation of enterprises, has become an important challenge for the survival and development of enterprises. The key to solve this problem is to get through the internal process of the enterprise, realize the digitalization and automation of business process, and improve the work efficiency of employees.

Under this condition, robot process automation (RPA) emerged, and it is considered as an effective way to solve the abovementioned problems [7]. RPA used virtual software robots to replace human and interact with existing user systems through preset programs to simulate and execute the established business processes [16]. As such, the regular rule-based operations can run automatically, and human can free themselves from boring and tedious repetitive tasks to innovative and challenging works. According to Markets and Markets, the global RPA market will grow at a compound annual growth rate of 30.14% from 2017 to 2022, reaching U.S. $2467 million by 2022.

RPA is used for automatic processing of relatively stable business processes with clear business rules, repeated execution, and large business volume. The emergence of RPA can not only reduce the human cost of enterprises but also improve the efficiency of business process execution and work efficiency of employees through automatic technical means. RPA plays an important role in enterprise digital transformation and improving business efficiency [20]. For enterprises, it can rapidly promote the automation process of the business process, reduce the operation cost and create value continuously, and thus can increase the core competitiveness of the enterprise. For employees, it can help them get from a large number of repetitive and tedious work, deal with their affairs more effectively, and make them focus on high-value work, so as to improve their production efficiency greatly.

However, RPA technology can only deal with simple and repetitive work but lacks intelligence. With the development of artificial intelligence (AI), blockchain, and other technologies, the combination of RPA with AI and blockchain will become a major trend in the future [10]. Therefore, our aim is to apply AI and blockchain technology in RPA to realize intelligent process automation (IPA), which has the intelligence of "thinking, learning, and decision-making" as human beings. With IPA, all the enterprises in the future will be intelligent enterprises.

V. BLOCKCHAIN-BASED DAO: THE NEXT GENERATION OF MANAGEMENT

A. DAO: A Decentralized Management Model

Traditional organization management follows a top–down pyramid structure, and it has many problems, such as overstaffing, multilevel management, high management cost,

unclear responsibility definition, poor information transmission, power concentration at the top and low autonomy at the bottom, and difficulty in effectively release innovation potential. With the development of information technology and the increasing complexity of the organization, the traditional employment relations and management model of organizations have become very difficult to adapt to the complex and changing environment and the requirements of the new generation of individuals to the organizations.

With the emergence and rapid development of blockchain technology and smart contracts [2], [9], [30], DAO has become a new modern organization management mode. In DAO, the management and operational rules are encoded on blockchain and can autonomously execute through smart contracts. It can realize self-operation, self-governance, and self-evolution in accordance with the preset rules using intelligent management means and economic incentives of certification, so as to achieve the maximized efficiency and value flow of the organization. DAO combines decentralization and autonomy with the economic incentive and takes all elements in the system as assets. It integrates monetary capital, human capital, and other elements capital to better stimulate the efficiency of the organization and realize the value circulation. It provides a feasible idea for solving the existing organizational management problems. As such, DAO is expected to become a new and effective organization form, which can deal with uncertainty, diversity, and complex environment and thus can be regarded as a new decentralized management model [27].

B. Management Model Based on DAO

Smart contract and DAO can greatly reshape the modern organizational management form. Smart contract can transform the management rules into "if–then" codes, and then, the organization can run independently according to these codes [26]. Every individual in the organization, including decision-maker, executor, and supervisor, can become the shareholder and participants of the organization by holding the equity of the organization or providing services to the organization. In DAO, each individual can participate in the governance of the organization, so as to fully stimulate individual creativity and improve the decision-making democratization of the organization. In addition, the management rules encoded in the smart contract are open and transparent, which also helps to eliminate corruption and misconduct. As such, DAO is regarded as a subversive change to the traditional "top–down" pyramid management form, which can effectively reduce the operating cost of the organization, reduce management friction, and improve the democratization of decision-making.

1) Distributed and Decentralized Management: Since there is no central node and hierarchical management architecture in DAO, the organizations can achieve their goals through bottom–up interaction, competition, and cooperation among network nodes with the help of DAO. Therefore, business transactions among nodes, between nodes, and organizations in DAO are no longer determined by administrative affiliation but follow the principles of equality, voluntariness, reciprocity, and mutual benefit. It is driven by each other's resource, advantages, and interests. Each organization node will cooperate effectively under the role of the incentive mechanism of token according to its own resource advantages and ability, so as to reach a strong synergy effect.

2) Autonomous and Automated Management: In DAO, management is coded, programmed, and automated. Code is law. Organizations are no longer in a pyramid structure with a centralized power, and it becomes distributed and decentralized. Management is no longer hierarchical but community autonomy. Organizations are replaced by highly autonomous communities. In addition, since the operation of DAO is under the standard and cooperation mode determined by the stakeholders, the consensus and trust within the organization are easier to reach, which can minimize the trust cost, communication cost, and transaction cost of the organization.

3) Organized and Ordered Management: Depending on the smart contract, the operation rules, responsibilities, and rights of the participants and the reward and punishment mechanism in the DAOs are open and transparent. In addition, through a series of efficient principles of autonomy, the rights and interests of relevant participants are precisely differentiated and dimensionally reduced, that is, to match the corresponding rights and benefits to those individuals who pay labor, make contributions, and bear responsibilities, so as to promote the division of labor and the equality of rights, responsibilities, and interests and make the organization run more coordinated and orderly.

4) Intelligence and Tokenized Management: Based on the blockchain technology, AI, big data, and IoT, DAO realized digitalization, intellectualization, on-chain and off-chain collaborative governance, which can greatly change the traditional bureaucratic system and management mode and realize the intelligent management of the organization. As an important incentive means in the process of DAO governance, token makes all elements of the organization such as individuals, knowledge, events, and products more tokenized, and it can fully integrate monetary capital, human capital, and other element capital and better stimulate the efficiency of the organization and realize the value circulation.

C. Real-Time Management and Performance Evaluation Based on Smart Contact

Smart contracts provide an important guarantee for enterprises to realize real-time management and real-time performance evaluation. The smart contract records the operation and management rules of the enterprise, as well as the work contents, evaluation standards, and performance evaluation indicators of employees in the form of computer code on the blockchain. All parties complete their work according to the smart contract and distribute the benefits according to their contributions and finally realize the real-time intelligent management and performance evaluation with "code is law."

DAO has the ability to implement the terms of the smart contract automatically. It puts consensus first, lock-in trust, and embeds law in the contract and can solve the contract problem of "Coase Theorem–Contract Theory–Property Right Theory–Transaction Cost Theory" in traditional

economic management. As such, it can greatly reduce the accounting cost and solve the problem of information asymmetry, which evolves the organization from negative sum and zero-sum games to positive-sum games in the governance and business processes. DAO runs on the decentralized processing and storage carrier, and with related technologies, it can match and connect human, organizations, knowledge, events, products, or services, so as to realize the real-time management and performance evaluation.

In addition, the smart contract is no longer limited to the automatic execution of predefined "if–then" rules but also has the functions of intelligent deduction, computational experiments, and independent decision-making in unknown scenarios with "what-if" rules, which made DAO a distributed autonomous organization with the ability of description, prediction, and prescription. With the real-time status data, intrachain transaction data, and system operation data of DAO nodes running in the blockchain system, we can predict the evolution pattern and development trend of DAO. Through digital description, prediction, and prescription, it can realize intelligent matching, management, and decision-making.

Blockchain technology is expected to realize the decentralized and software-defined social system. In particular, smart contracts can be used to deploy various management rules, reward, and punishment standards in the form of programmed code on the chain, and any organizations and individuals must follow these rules. In this way, it is expected to transform "Merton" social system into "Newton" social system, which can be observed comprehensively, controlled actively, and predicted accurately. ACP approach can be combined with blockchain and smart contract, which can be used to realize parallel social management driven by smart contract. First, each node in blockchain is an autonomous and autonomous one in a distributed system, and many agents will form various types of DApps through smart contracts. These DApps will form specific organizational forms of DAO and finally aggregate into the Decentralized Autonomous Society (DAS). Second, the intelligence of smart contract enables it to carry out all kinds of "what-if" computational experiment design, intelligent deduction, and result evaluation, so as to observe and evaluate the performance of all kinds of parameter configuration, functional modules, and architecture in different experimental scenarios and predict the evolution trend. Finally, the intelligent assets formed by the combination of blockchain and IoT make it possible to connect the real physical world and virtual cyberspace. Through the interaction and parallel execution of the real and artificial social system, the collaborative optimization of social management and decision-making can be realized.

VI. Case Study

We instantiate our proposed CPSS-oriented parallel management framework in an enterprise in China, which has more than 300 employees, with the help of a social media platform called WeChat. The data of the employees, including static data such as their educational background, work experiences, skill levels, and project experiences, and dynamic data such as

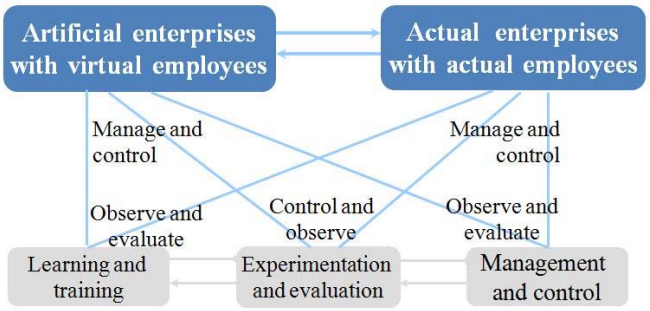

Fig. 5. CPSS-based parallel enterprises.

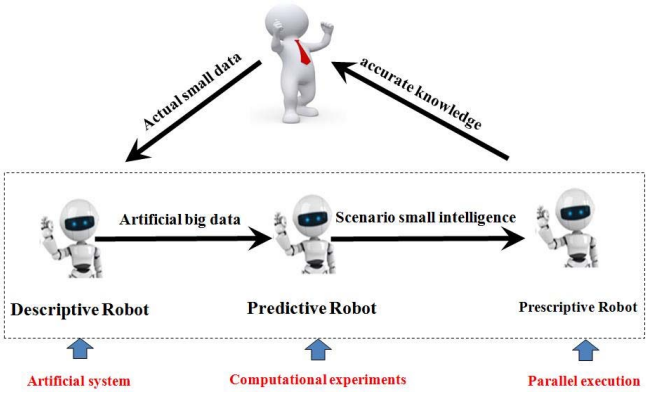

Fig. 6. Three robots for each employee.

their behaviors and work reports, are stored on the blockchain. The company's rules, including the work requirements, work content, evaluation indicators, reward, and punishment regulations, are written in the smart contract.

Using these static and dynamic data of enterprises and employees, we build an artificial enterprise with virtual employees that run in parallel with the actual enterprise and employees (as shown in Fig. 5) based on the ACP approach [21] and build three robots for each employee [29], that is, descriptive robot, predictive robot, and prescriptive robot (as shown in Fig. 6). The descriptive robot of each employee can illustrate what the position is responsible for, the predictive robot can show what will happen with his behaviors, and the prescriptive robot can suggest what the optimal behavior is. Through the artificial enterprise and virtual employees, we can generate virtual big data from actual small seeding data, and then, the "big data" can be refined into "small intelligence," so as to form the real-time interactive parallel employees of virtual and parallel enterprises and realize the real-time management and performance evaluation of the employees according to the smart contract.

In the abovementioned system, 12 indexes are adopted from four dimensions to evaluate the employees' performance, including attendance rate, report rate, report length, work diversity, achievements, key emphasis, report time, teamwork engagement, and report sentiment. With the data extracted from the system according to these indexes, the employees' work strategies, especially the work time determination, can be optimized, which can maximize the total utility of

the enterprise. It has been proved that the optimal work time is always the threshold work time to achieve a higher level or a better rank, and with the increasing of the optimal work time, the maximal total utility decreases first and then increases. These results can provide meaningful managerial insights for the employees to manage their work strategies, especially the work-time optimization [8].

VII. Conclusion

In this article, we applied the blockchain technology in knowledge automation and proposed blockchain-based knowledge automation. We discussed the requirements for enterprise management caused by UDC of enterprise and proposed a framework of parallel management based on CPSS and knowledge automation to realize AFC, which is effective in solving the problems in CPSS-oriented enterprise parallel management. We also proposed a management model based on DAO, in which real-time management and performance evaluation of employees can be realized based on smart contact. We also utilize our proposed framework in an enterprise in China, to illustrate the effectiveness of our framework.

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