

# A Blockchain-based Framework for Collaborative Production in Distributed and Social Manufacturing

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**Abstract**—In recent years, novel collaborative production paradigms, such as (re-)distributed manufacturing and social manufacturing, have attracted intensive attention due to their potential of further changing the existing manufacturing modes and industrial structures. Blockchain, as a new distributed computing architecture, is expected to be successfully used in manufacturing, and help solve issues related to interoperability and collaboration, security and supervision, marketization and protocol, democratic organization and global value chain governance, and so on. In this paper, a blockchain-based framework for collaborative production is proposed, aiming at providing novel ideas for the design, implementation and optimization of collaborative production, and also inspiring the upgrading and transformation of manufacturing industries.

**Index Terms**—distributed manufacturing, social manufacturing, collaborative framework, blockchain, smart contract

## I. INTRODUCTION

In order to reduce costs and improve efficiency, traditional manufacturing mode often adopts standardized and centralized mass production and mass customization. In this way, the fixed enterprise configuration is difficult to be modified, expanded and integrated, the limited product model is difficult to meet the individual needs of users, and the poor system flexibility is difficult to satisfy the dynamics and uncertainties of production task management [1]. Recently, with the formation of the global market and the advent of the digital economy era, product market and customer demand are continuously subdivided, the social networks of division of labor and cooperation are constantly improved and the customer-oriented personalized product development becomes a new trend. Also, with the support of emerging technologies such as big data, Internet of Things, cloud computing, artificial intelligence, 3D printing and RFID, fine and modular collaborative production mode like Distributed Manufacturing (DM), Re-distributed Manufacturing (RdM) and Social Manufacturing (SM), which can effectively break through geographical constraints, fully connect social resources, deeply excavate the value of long tail, greatly enhance the production flexibility and core competitiveness of enterprises, becomes possible.

Although the prospects of these collaborative production modes are broad, they need to meet the multi-dimensional

requirements of technology, service, infrastructure and resources. Especially, with the gradual maturation of related component, there is always a lack of a large-scale, highly connected, secure and trusted digital infrastructure to efficiently integrate all key technologies and core elements. Blockchain, as a hot new distributed computing paradigm with the characteristics of decentralization, time series, collective maintenance, programmability, security and credibility, is expected to become an ideal digital infrastructure for integrating all intelligent components and organizations of the above collaborative production system. Furthermore, combined with blockchain-enabled smart contracts, programmable assets, systems and society can be constructed to achieve safe and efficient information exchange, value transfer and asset management, and ultimately to deeply transform the existing business model and social production relations.

Since DM, RdM and SM are all new but not fully realized concepts now, many scholars have proposed some conceptual model and frameworks to guide and accelerate their construction [2] [3] [4]. However, the effect of blockchain was never considered. As an early attempt in this field, on the basis of existing work, this paper first classifies the difficulties in realizing the above production mode into five categories: interoperability and cooperation, security and supervision, marketization and protocol, democratic organization and global value chain governance. Then, for these difficulties and their corresponding blockchain solutions, combined with the processes, modules and key technologies of the above production mode, a new collaborative production framework using blockchain as the digital infrastructure is proposed for the first time. On the one hand, the framework aims to cover the specific direction and technology that blockchain can be used to optimize the current manufacturing, and on the other hand, it provides a new design idea of building collaborative manufacturing system based on blockchain.

The paper is organized as follows: Section 2 reviews the literature, introduces the basic concepts; Section 3 summarizes the difficulties; Section 4 proposes the blockchain-based collaborative production framework and illustrates it with practical application examples; Section 5 concludes.

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## II. LITERATURE REVIEW

### A. Blockchain

As the underlying technology of Bitcoin, blockchain in forms of chained data blocks is a distributed ledger shared and maintained by each node in the decentralized system [5]. In blockchain system, nodes (also called miners) connected and interacted through P2P network are motivated by incentive mechanism to contribute their computing power to execute, verify, package and disseminate transactions generated over a period of time. At the same time, miners strive for the accounting right according to consensus mechanism and the winner can connect its own committed block to the main chain and get the corresponding reward, and then the rest of the nodes accept the updates. Generally, blockchain can be divided into public blockchain, private blockchain and consortium blockchain based on their permission model.

The term “smart contract” was first coined in 1994 by the computer scientist and cryptographer Nick Szabo, who defined a smart contract as “a set of promises that are specified in digital form, including protocols within which the parties perform on these promises.” [6] Concretely, blockchain-enabled smart contracts can be regarded as the computer programs on distributed ledger with states, preset rules and conditional responses, they can encapsulate, verify and execute complex behaviors of distributed nodes to realize information exchange, value transfer and asset management. As computer transaction protocols that can self-verify and self-enforce the terms and conditions without intermediary, digital smart contracts can be embedded in various assets, transactions and data, so as to act as trusted agents to efficiently and safely execute contracts and create a variety of intelligent assets and systems.

Blockchains and blockchain-enabled smart contracts both have the characteristics of de-trust, decentralization, autonomy, anonymity, traceability and tamper-resistance, and have shown broad application prospects and attracted wide attention. At present, they have been applied in medical, financial, Internet of Things and many other fields [7].

### B. Distributed Manufacturing

Distributed manufacture(DM) system is a production system consisting of small-scale manufacturing units based on new physics, digital and communication technologies. By localizing manufacturing facilities and communicating instantly in supply chain, it promotes customer-oriented mass customization and increases system flexibility, adaptability, agility and robustness [8]. DM becomes RdM when DM system can responds to ecological needs to redistribute the manufacturing location, scale, standards, value, risks and responsibilities of distributed sites or agents [9]. Considering that RdM is still a derivative concept of DM at the present stage, and the proposed collaborative model is universal, these two concepts will not be distinguished in the following and collectively referred to as DM.

DM is characterized by digitalization, localization, personalization, democratization and sustainability [10]. Digital integration of the whole production cycle and logistics

transportation will allow products to exist in virtual form and be produced as required without geographical restrictions whenever local production resources are available and production technology is accessible. Digital design and sharing of products will promote open innovation driven by data, the functions of stakeholders will be redistributed in the process, customers will become co-creators of value fully involved and the complete value chain will be democratized. Organizations and enterprises will achieve sustainable development in all dimensions of economy, ecology, society and politics [11].

### C. Social Manufacturing

Social manufacturing(SM) was first put forward by the Economist magazine in its special report “The Third Industrial Revolution” in 2012. They believed that with the maturity of 3D printing, there would be a new manufacturing mode in which everyone could participate in the manufacturing, i.e., SM, and that would set off a new wave of industrial revolution [12]. Fei-Yue Wang clarified the concept for the first time [13] and expanded later [14]: SM refers to a new distributed, networked and socialized manufacturing mode driven by the crowdsourcing of professional services on the basis of sharing and self-organization of socialized manufacturing, service and resources. It adopts new technologies such as Internet of Things, Cloud Computing, Big Data and 3D Printing to optimize the sharing and organizing of human, financial and material resources in the social network environment.

The term “social” mainly refers to the utilization of social resources, the self-organization of social community and the support of social media [3]. In SM, global consumers, producers and providers can fully participate in the life cycle of personalized products through collaborative interaction with various resources and communities on the SM network or platform, thus the social needs and resources can be properly matched in time and the large centralized enterprises are decomposed into small flexible groups of design, produce, logistics and services [15]. In a word, the characteristics of SM can be summarized as personalization, localization, socialization, demand-driven and decentralization.

It is not difficult to find the similarities between SM and DM from its definition, characteristics and goals. The difference is that SM emphasizes the role of communities based on social media and networks, as well as the relationship between individuals and organizations (communities) [16]. With the development of information technology and the enrichment of network activities, the traditional Cyber-Physical Systems (CPS) have been expanded to people-oriented, physical world and cyberspace merged Cyber-Physical-Social Systems (CPSS) [17] [18], and the Cyber-enabled Movement Organizations (CMOs) that can depict the behaviors of dynamic netizens becomes the key [19]. CMOs in SM can be further interpreted as Customer Movement Organizations, i.e., a community composed of a large number of prosumers with common interests and tasks. Individuals can freely choose to interact independently or in a community, so as to ensure the openness, inclusiveness,

flexibility, dynamic stability, self-organization and self-adaptability of SM networks [20].

### III. THE DIFFICULTIES IN COLLABORATIVE PRODUCTION

Due to the limitation of technology and resources, there are still many challenges in the practical application of DM and SM [10] [21]. Considering their challenges are similar and have common blockchain solutions, this paper reviews literature, classifies the difficulties into five categories: interoperability and cooperation, security and supervision, marketization and protocol, democratic organization and global value chain governance and introduces them separately.

**(1) Interoperability and cooperation:** including access difficulties for individuals and Small and Medium-sized Enterprises (SMEs), multi-agent interaction difficulties, task planning difficulties and resource scheduling difficulties. Generally, large enterprises that occupy the leading position are more likely to form alliances to monopolize related technologies and markets. When multiple agents with different production capacity complete production tasks in distributed locations, they need instant and efficient interactive networks to help accurately transmit production information, rationally plan production tasks, and make full use of resources without conflicts. SM emphasizes the interaction and collaboration between parties and the resource allocation and tracking in crowdsourcing and outsourcing. These dynamic management of network citizens, social resources and production services are called information collaborative management, which is hard to realize by traditional social media [22].

**(2) Security and supervision:** including the identity authentication difficulties, data security storage and sharing difficulties, intellectual property and other legal rights protection difficulties and supervision and audit difficulties. With the gradual expansion of the scale of collaborative production system, data leakage and identity theft will make node identity authentication more and more difficult, the joining of false and malicious nodes will endanger the interests of honest nodes. At the same time, when the transportation of physical products turns to the transmission of product data, the safe storage and sharing of data that includes all the key information is essential. Only in a data transaction environment where legal rights such as intellectual property rights and ownership are clearly defined, enterprises and individuals are encouraged to participate spontaneously in open innovation and co-creation. In addition, reliable certificate systems can solve the problem of forensics and supervision of multi-attribute multi-interest group interaction.

**(3) Marketization and protocol:** including individual users and production intermediaries participation difficulties, personalized agreements reach difficulties and risks imputation difficulties. In an ideal DM system, even individual customers should be able to reach legitimate and compliant production agreements with relevant production units, or the products individuation will be greatly limited. Therefore, the demand for production intermediaries, individuation agreements and

order negotiation market are particularly strong. Currently, there is no interactive market that can connect designers, production units, production intermediaries and end users. Production intermediaries as a future profession, still need to be digitized, and order agreements need to be formulated in a more free, standardized, concise, intelligent and credible way. For SM, the difficulty lies in the match of social demand and manufacturing capability in real time and the lack of guarantee mechanism.

**(4) Democratic organization:** Decentralized flat production interconnection mode and organizational form are the most important characteristics of DM and SM. With the redistribution of the functions of stakeholders and the democratization of the complete value chain, new organizational and business mode will inevitably emerge and their governance becomes significant. The present centralized pyramidal structures is obviously unsuitable for distributed systems for their shortcomings such as overstaffed organizations and coordinate difficulties. When the connection between CMOs in SM increases, the leading enterprises no longer have the dominant power in the manufacturing network, and the traditional producer-oriented market gradually shifts to customer-oriented market. Then the openness, creativity, productivity, and value-adding capabilities of the CMOs become decisive factors in determining the efficiency, which means their governance is also crucial.

**(5) Global value chain governance:** global value chain refers to the global cross-enterprise network organization that connects production, sales, recycling and other processes to realize the value of goods or services. It includes the organizations of all participants and activities, as well as their value and profit distribution. Companies around the world in the global value chain carry out various value-added activities including design, development, manufacturing, marketing, sales, consumption, after-sales service, and recycling [23]. Different value chains should have different operational rules and governance frameworks to guide industrial upgrading and improve economic. Collaborative production systems will change the main drivers, economic structures and value-added mechanisms of existing global value chains, therefore a flatter, concise, precise and unified analytical governance framework is required.

In order to solve the above difficulties, a blockchain-based collaborative production framework is proposed and elaborated in Section 4.

### IV. THE BLOCKCHAIN-BASED COLLABORATIVE PRODUCTION FRAMEWORK

Considering that the characteristics of blockchain technology have great potential in solving the difficulties of DM and SM, a collaborative production framework using blockchain as digital infrastructure is proposed in this paper. As shown in Fig. 1, the framework is constructed in the order of the blockchain-based collaborative production process and value flow, specifically, from the bottom to the top, it is divided into five layers: resource service layer, network interconnection layer, market agreement layer, collaborative management layer



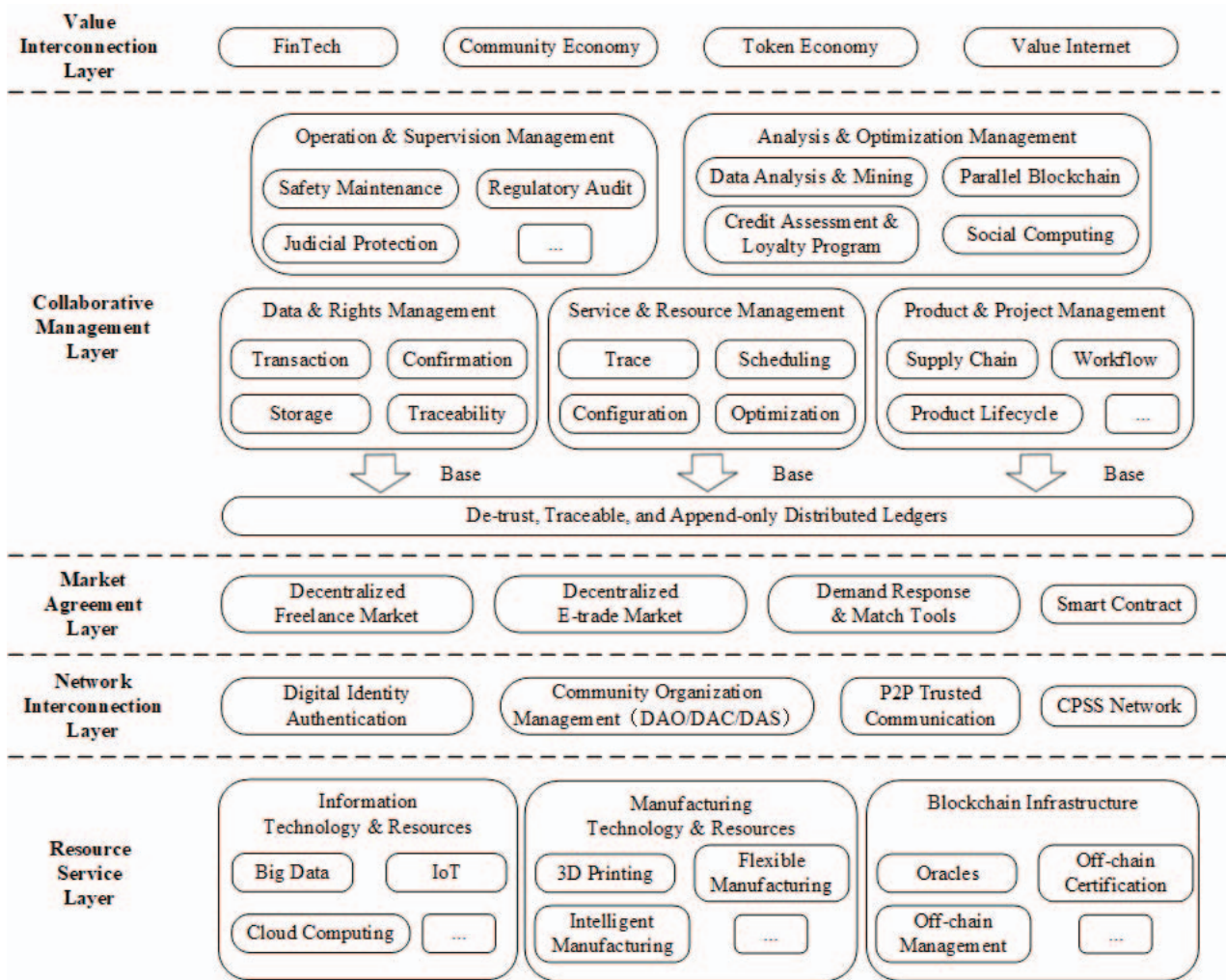


Fig. 1. The blockchain-based collaborative production framework.

and value interconnection layer, which almost corresponds to the difficulties summarized in Section 3. The elements in the model are the key technologies and blockchain optimization solutions involved in the manufacturing process, they are not limited to the collaborative mode but can be widely used in general manufacturing systems. The following introduce the model in layers with practical application examples.

#### A. Resource Service Layer

Resource service layer includes information technology & resources, manufacturing technology & resources and blockchain infrastructure, which are required by DM and SM and supporting all the complex at the upper level, such as data analysis and mining, social computing, and community organization management. Among them, the blockchain infrastructure mainly refers to the off-chain and cross-chain facilities, including oracles, off-chain management and off-chain certification. They are the interaction foundation of blockchain to blockchain and blockchain to the real world. For example, one of the drawbacks of blockchain is that it can only guarantee that the data is not tampered with, but not

necessarily “true”. The off-chain certification service can help to distinguish the authenticity, such as the off-chain real-name authentication of a designated notary before an individual obtaining the digital identity on the chain. In addition, the oracle is the external trusted data feeds of blockchain and the off-chain management ensures the stability and safety of blockchain ecology by proposals, votes, updates, soft and hard forks.

#### B. Network Interconnection Layer

Network interconnection layer includes digital identity authentication, community organization management, P2P trusted communication and CPSS network, based on which the DM or SM network, i.e. CPSS network in this paper, can be built and their interactive process is shown in Fig. 2. Enterprises, users and devices become trusted nodes after being assigned digital identities and then construct a blockchain-based CPSS network.

There are many blockchain-based digital identity authentication systems already, such as IDhub [24], e-Resident [25] and so on. In blockchains P2P network, all nodes

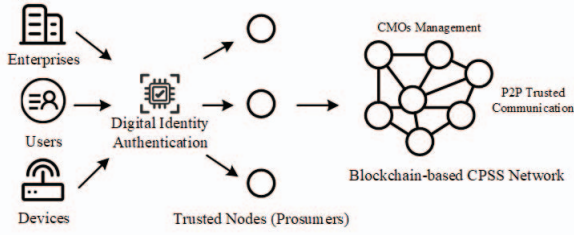


Fig. 2. Network interconnection process.

are equal peers connected in a flat topology, which means there is no centralized hierarchical structure, individuals or SMEs can freely access the network and undertake production tasks without the restriction of their own capacity. Based on blockchain and smart contracts, various kinds of decentralized autonomous organization (DAO, also known as decentralized autonomous corporation, DAC) and decentralized autonomous society (DAS) can be evolved. DAO enables every individual to participate in the governance of the organization, thus stimulating individual creativity, reducing the management friction and costs, and improving the democratic decision-making. DM, as a natural decentralized organization, has the potential to realize intelligent autonomy relying on DAO. Also, the term “community” can completely correspond to the DAO and DAOs governance will be a good reference for community.

### C. Market Agreement Layer

Market agreement layer includes decentralized freelance market, decentralized E-trade market, demand response & match tools and smart contract, based on which a supply-demand matching and crowdsourcing outsourcing market lack in SM can be constructed, so as to help prosumers securely and credibly reach a cooperation agreement and solve marketization and protocol difficulties.

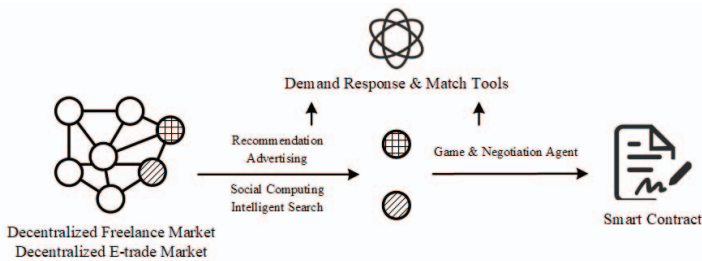


Fig. 3. Interaction in market agreement layer.

Fig. 3 shows the interaction, among them, demand response & match tools include existing modules such as personalized recommendation, advertising, social computing and intelligent search, as well as emerging concepts such as production intermediaries and game and negotiation agent. Blockchain-based collaborative production adopts smart contracts instead of traditional contracts, analogous to the existing decentralized E-trade market like Slock.it [26], decentralized freelance market like Gitcoin [27] and decentralized crowdsourcing

platform like CrowdBC [28], to establish personalized order negotiation market as a supplement to multi-parties free and fair cooperation. Because smart contracts can be regarded as users software agents or robots in blockchain, they can be used as the digitalization of the traditional agent in distributed scheduling problem or the future production intermediaries, their tamper-resistance and self-enforce characteristics will be conducive to the risk liability.

### D. Collaborative Management Layer

To solve the difficulties in interoperability, cooperation, security and supervision, collaborative management layer includes 5 modules: data & right, service & resources, product & project, operation & supervision and analysis & optimization.

Blockchain incentive compatible crowdsourcing mechanism creates a natural and free game environment for collaborative production parties [29]. The characteristics of de-trust, traceability and tamper-resistance ensure the reliability of data and information, the security of storage and transaction, and the traceability of resources, tasks and responsibilities [30]. Thus, the planning system can avoid resource conflicts, accurately make decisions and efficiently schedule. Digital copyright authentication and transaction systems and electronic certification systems can protect intellectual property and other legal rights and help supervise and audit. Smart contracts can optimize the Internet of Things and supply chain by providing a trusted interactive and real-time visible environment, automating complex processes, reducing the risk of fraud and theft, and ensuring security and efficiency [31] [32]. Credit assessment and loyalty program are powered by tamper-resistant records and flexible cryptocurrencies [33]. In addition, parallel blockchain based on parallel intelligence theory and ACP method (Artificial systems + Computational experiments + Parallel execution) can be used as “computing laboratory” of real blockchain, offline trial-and-error experiments and rational deliberation in artificial blockchain under normal conditions can guide real-time management and decision-making of real blockchain under abnormal conditions [34] [35] [36].

### E. Value Interconnection Layer

Value interconnection layer includes FinTech, community economy, Token economy and value internet, which are corresponding to the global value chain governance difficulties. As a globally shared distributed ledger, blockchain can transfer value while transmitting information, which ensures the integrity, authenticity and uniqueness of the value transmission process, reduces the risk and improves the efficiency. Blockchain is expected to transform the information internet into the value internet, thus completely reshaping the pattern of human social activities like the internet. Based on blockchain value transmission carrier Token and Token system, the contribution of all participants to the collaborative production system and their global value chain will be quantified and settled automatically. All participants will share the added value fairly, and the Libra from Facebook could be the first try to this aim [37]. At the same time, the emerging economic organizational

mechanisms such as Token economy, shared economy and community economy will also provide more feasible solutions for the evolution and governance of global value chains in DM and SM.

## V. CONCLUSION

As an early attempt to apply blockchain in the field of DM and SM optimization, this paper proposes a collaborative production framework using blockchain as the digital infrastructure and provides a new idea of collaborative production design, which can efficiently solve the difficulties existing in current systems such as interoperability and collaboration, security and supervision, marketization and protocol, democratic organization and global value chain governance. In order to make up for the lack of frameworks implements, this paper combines the frontier blockchain applications to explain the framework comprehensively, demonstrates the specific operation mechanism, and embodies the feasibility. DM, SM and blockchain are all emerging research directions and large-scale systems or architectures, their related key technologies such as social computing, smart contract and cross-chain technology still need to be further studied and improved. Therefore, a forward-looking production framework for future integration before that is instructive.

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