An Exploration of Blockchain Technology Driving Knowledge Management in Industrial Clusters: Postprint

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Abstract

[Purpose / Significance] The complexity of knowledge network nodes in industrial clusters determines the high difficulty of knowledge management within industrial clusters, while the unique advantages of blockchain technology provide a promising research direction for knowledge management within clusters. [Method / Process] Through literature review, this paper systematically elaborates the composition and characteristics of knowledge network nodes in industrial clusters, and based on the four fundamental processes of knowledge management, discusses in detail how to utilize blockchain technology to promote knowledge management within industrial clusters and the application models of blockchain technology in the knowledge management process of industrial clusters, thereby achieving the goal of solving current common problems. [Results / Conclusion] The technical features of blockchain provide practical technical solutions for processes such as knowledge creation, knowledge storage/indexing, knowledge transfer, and knowledge application within industrial clusters, and offer a new entry point for removing obstacles to knowledge management within industrial clusters.

Full Text

Preamble

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Abstract

[**Purpose/Significance**] The complexity of knowledge network nodes in industrial clusters determines the high difficulty of knowledge management within such clusters, while the unique advantages of blockchain technology provide a promising research direction for addressing these challenges. [**Method/Process**] Through literature review, this paper systematically elaborates on the composition and characteristics of knowledge network nodes in industrial clusters. Based on the four fundamental processes of knowledge management, it explores in detail how blockchain technology can promote knowledge management within industrial clusters and proposes an application model for blockchain technology in this context, aiming to solve common existing problems. [**Result/Conclusion**] The technical characteristics of blockchain offer practical solutions for the processes of knowledge creation, knowledge storage/indexing, knowledge transfer, and knowledge application within industrial clusters, providing a new entry point for overcoming obstacles to knowledge management in these environments.

Keywords: blockchain technology, industrial cluster, knowledge management

1. Introduction

In 2016, China's Ministry of Industry and Information Technology released the *White Paper on Blockchain Technology and Application Development in China*, and in the same year, blockchain technology was included as a strategic frontier technology in the *13th Five-Year National Informatization Plan* by the State Council. Since then, research literature on blockchain in China has grown rapidly [1]. The birth of blockchain is considered the beginning of humanity's construction of a value transmission network, enabling value to be transferred as quickly, conveniently, and cost-effectively as information is transmitted over the internet today. The forms of value transferred can be funds or assets, but also other forms such as knowledge [2]. Consequently, blockchain technology has been identified in McKinsey research reports as a potentially disruptive next-generation core technology, following steam engines, electricity, and the internet. Blockchain applications have extended not only to healthcare, law, copyright, asset management, and media but also have positive implications for the field of knowledge management.

Current research on blockchain can be broadly categorized into three areas: (1) **Technical research on blockchain itself.** S. Feld et al. proposed a resilient Bitcoin ecosystem based on the original blockchain working principles [3]; J. H. Ziegeldorf et al. improved the Bitcoin blockchain protocol algorithm and conducted empirical validation [4]; G. Greenspan conducted comparative studies on the working mechanisms among Bitcoin, centralized databases, and Ethereum [5]; Han Xuan et al. conducted comprehensive analyses of blockchain security issues and proposed a parallel security conceptual framework for blockchain

[6]. (2) **Reflections on blockchain technology and its applications.** A. Walch argued that with the involvement of cryptocurrencies, smart contracts, and new management ideas, blockchain's verified technical characteristics may disrupt future legal frameworks [7]; Chen Liyang suggested that neither technical nor legal tools alone are sufficient to fully explain the knowledge attributes of blockchain, proposing the use of knowledge engineering as a new form for legal reflection on blockchain research [8]. (3) **Research on the application value of blockchain.** Foreign scholars have studied blockchain application value across numerous domains, with extensive literature covering finance, supply chains, stocks, the Internet of Things, and government organizations. Domestic scholars have focused primarily on the financial sector [1], but since 2016 have begun exploring blockchain applications in other fields such as education, knowledge management, government and social management, library and information science, and cybersecurity. These rich research findings in recent years provide ample theoretical support for this study.

2.1 Introduction to the Technical Characteristics of Blockchain

Depending on the application scenario, blockchain technology has evolved into three modes with varying degrees of decentralization: public chains, consortium chains, and private chains. Its technical system generally consists of a data layer, network layer, consensus layer, smart contract layer, and application layer [15], where each blockchain system must include the data layer, network layer, and consensus layer, while other components can be added according to specific scenario requirements.

Overall, the technical characteristics of blockchain can be summarized into five aspects [16]: (1) **Decentralization:** Unlike internet systems, blockchain is a decentralized system without a central authority. Daily operation and maintenance rely on each node in the system, with every node having equal rights and obligations. (2) **Strong openness:** All data information in the system is public and transparent. Participants who know the node location and obtain the key can access the stored data information from any node. (3) **Trustlessness:** In blockchain systems, all data recording and reading occur under strict machine language rules that cannot be interfered with by anyone, thus achieving trustless operation. (4) **Immutability:** According to the design philosophy of blockchain systems, modifying data requires controlling more than 51% of the nodes, which is virtually impossible for any single participant. (5) **Traceability:** Data information in blockchain systems is formed in chronological order, with a chain-like structure that ensures data reliability and stability.

2.2 The Complex Composition and Characteristics of Knowledge Network Nodes in Industrial Clusters

Industrial clusters consist of geographically proximate companies and related institutions with complementarity and commonality in specific business domains. They reduce transaction costs, enhance competitiveness of participants, and offer greater flexibility [17], representing a new form of organizational space. Industrial clusters promote rapid regional economic development and have become an important force for countries and regions participating in the international economy. Relationships among cluster members exist in network form [18]. Generally, knowledge network nodes in industrial clusters are considered to mainly include cluster enterprises, government, cluster knowledge innovation-oriented service providers, and professional service providers.

2.2.1 Cluster Enterprises

Cluster enterprises are the basic units and main actors of industrial clusters. Their nature and characteristics determine those of the entire cluster, making them core elements of the cluster's knowledge management network that directly determine knowledge integration and upgrading. Cluster enterprises are both the fundamental units and primary bearers of knowledge management and innovation. Based on their role in the cluster, they can be divided into core enterprises and non-core enterprises.

2.2.2 Government

In the knowledge network of industrial clusters, government often plays a bridging role by actively participating in and creating an innovation atmosphere, making knowledge transfer and diffusion more effective. Although geographically government does not exhibit spatial agglomeration, its role in the formation and development of industrial clusters is enormous, making it an indispensable node in the cluster's knowledge network.

2.2.3 Cluster Knowledge Innovation-Oriented Service Providers

The role of cluster knowledge innovation-oriented service providers is typically undertaken by universities and research institutions. These institutions are often sources of knowledge creation and high-quality labor generation. The flow of their reserved knowledge to enterprises forms a positive feedback loop, representing an important knowledge flow in innovation networks [19]. In addition to creating new technologies, knowledge, and ideas, universities and research institutions can effectively achieve knowledge diffusion or market value through transformation, education, and training, providing guidance for the innovation direction of industrial clusters.

2.2.4 Professional Service Providers

Professional service providers are important pillars of knowledge innovation in industrial clusters and crucial links promoting knowledge flow or technology diffusion among various nodes. They mainly include various firms, associations, financial institutions, and human resources training organizations. These providers offer specialized services to cluster enterprises, combining public service characteristics with market flexibility. They can effectively activate market resources, promote close cooperation among industry, academia, and research, accelerate the spread and diffusion of tacit knowledge within clusters, and assist cluster enterprises in solving various professional problems encountered during innovation, thereby facilitating the establishment of cluster knowledge innovation networks.

The knowledge network nodes and knowledge flows within an industrial cluster are illustrated in Figure 1 [Figure 1: see original paper], which clearly shows that knowledge flows among nodes are complex, with each node playing complicated roles, all of which pose considerable challenges for knowledge management within the cluster.

3. Promoting Knowledge Management in Industrial Clusters through Blockchain Technology

Knowledge management is a process involving multiple activities. Individuals and organizations may participate in different processes of knowledge management at any time and in any part of the organization. Therefore, knowledge management is not a separate, discrete, self-contained organizational phenomenon. It includes four basic processes: knowledge creation (or "knowledge construction"), storage/indexing, transfer, and application [20], and the same applies to knowledge management in industrial clusters.

3.1 Promoting Knowledge Creation in Industrial Clusters through Blockchain Technology

Nonaka views knowledge creation as a continuous interaction between explicit and tacit dimensions of knowledge and a spiral growth flow of organizations from individual to group to organizational levels. He divides knowledge creation modes into four types: socialization, internalization, combination, and externalization [21], which are interdependent and benefit from each other. IT technology has deeply intervened in this process—for example, email systems and group support systems can promote knowledge creation [21]; computer simulation systems can assist individuals in converting explicit knowledge into tacit knowledge to achieve internalization; organizational forums or similar functions allow people to share and construct knowledge, improving the quality and frequency of knowledge creation [20].

Due to the complexity of knowledge network nodes, knowledge creation in industrial clusters has a stronger demand for IT technology. Ensuring the credibility and equal participation of various knowledge sources is crucial. Core enterprises in industrial clusters are more active in knowledge creation, generating significant knowledge spillover effects and dominating the network relationships within and outside the cluster [22]. Their role is considered critical, and they possess knowledge power over other enterprises [23]. Core enterprises may use their key technological knowledge advantages to promote R&D cooperation among cluster enterprises by advocating trust and cooperative sharing, thereby improving the overall knowledge creation level of the cluster, as seen in Toyota City and Seattle's aviation cluster. However, the decline of Germany's Ruhr industrial zone, with Ruhr Coal and Thyssen as core enterprises, also demonstrates that core enterprises may not advocate establishing R&D-based cooperative relationships to maintain relatively fixed production-supply relationships [24], leading to weakened cluster innovation capacity. If knowledge creation relies solely on spillovers from core enterprises while non-core enterprises remain followers, it will exacerbate factual inequality among cluster enterprises in knowledge creation and seriously affect healthy cluster development. Blockchain's distributed and transparent nature can ensure equal rights and obligations for all knowledge network nodes, guaranteeing their equal participation and improving the de facto unequal status between core and non-core enterprises in knowledge creation, thus preventing cluster innovation capacity from depending solely on core enterprises.

In the knowledge creation process, we must consider not only the impact of knowledge sources and states on knowledge creation but also favorable conditions for it, such as knowledge-friendly organizational culture, which has been identified as one of the most important conditions for successful knowledge management activities [25]. Analysis of existing blockchain research and applications reveals that blockchain can optimize services and transactions in trust-deficient environments [26]. For instance, its encryption algorithms enable verifiable and permanent recording of knowledge, thereby securing intellectual property rights through safe methods and allowing knowledge management activities to proceed in a trusted environment. When cluster knowledge network nodes use blockchain for knowledge creation, they can obtain traceable, guaranteed knowledge from the blockchain information platform for combination or internalization, enhancing trust in knowledge sources. Simultaneously, nodes can upload their unique knowledge to the platform for externalization or socialization while obtaining intellectual property protection, and even receive corresponding rewards through blockchain's incentive layer design. This virtuous cycle undoubtedly drives the organizational culture of cluster knowledge network nodes toward knowledge-friendliness, thereby improving knowledge creation efficiency.

3.2 Promoting Knowledge Storage/Indexing in Industrial Clusters through Blockchain Technology

Cluster knowledge network nodes continuously create and learn knowledge, making knowledge storage crucial for sustainable cluster development. However, knowledge is often forgotten, meaning its clues are lost. Current pain points in cluster knowledge storage include: (1) The complexity and diversity of knowledge network nodes result in varying knowledge storage/indexing capabilities, with non-core enterprises' storage capacity far inferior to that of core enterprises. (2) As understanding of the knowledge economy deepens, cluster enterprises increasingly invest in digital resource construction. From the cluster perspective, industrial clusters often feature massive distributed digital resource libraries and relational databases. However, different construction entities lead to disparate storage methods and data formats for heterogeneous data, preventing synergistic knowledge storage/indexing, let alone effective utilization of stored knowledge. (3) Knowledge storage is important for enterprise product and process development, and cluster enterprises have different knowledge storage routines [27]. The complex knowledge network nodes in industrial clusters determine even more complex, fragmented knowledge storage routines that affect storage/indexing efficiency.

Blockchain technology has unique advantages for knowledge storage/indexing in industrial clusters. Blockchain adopts a "decentralized" approach through distributed accounting and storage, where any node has equal rights and obligations without a central management authority. Data blocks are jointly maintained by all nodes, making everyone an information provider. This solves the initial source problem of knowledge storage/indexing, ensures diversity of stored knowledge sources, and in fact guarantees equality among cluster knowledge network nodes. Blockchain's "immutable, strongly endorsed, full-history" technology ensures knowledge storage security and strong traceability, allowing every step of indexed knowledge development to be tracked. This protects the rights of non-core enterprises in knowledge storage. The "openness and consensus" technology can maximize knowledge dissemination, making it multi-centered where any node can become a knowledge dissemination point, no longer limited to core enterprises' knowledge output. This smoothes knowledge flows among cluster nodes, greatly improves knowledge utilization rates, and resolves fragmented knowledge storage. The essential characteristics of blockchain technology align with big data mining of library mobile user behavior [29], and their effective combination can improve the intelligence of data mining, making knowledge indexing more efficient. The construction and use of blockchain among knowledge network nodes can compel cluster nodes to actively reflect on their knowledge storage practices and establish more effective routines.

3.3 Promoting Knowledge Transfer in Industrial Clusters through Blockchain Technology

Knowledge transfer in industrial clusters is an important process that can occur at multiple levels: between individuals, between individuals and teams, between teams, between teams and organizations, and between organizations. Ultimately, the core issue is knowledge transfer efficiency. All information in blockchain systems is public and transparent, and its strong openness enables all members in the system (whether individuals, teams, or organizations) to search for relevant knowledge conveniently, transcending the limitations of single organizations and avoiding self-imposed limitations from individuals simplifying knowledge coding into semantic memory [20], thereby improving transfer efficiency.

It is important to note the role of knowledge spillover effects in cluster knowledge transfer: while they accelerate knowledge diffusion among cluster knowledge network nodes and positively enhance industrial and regional competitiveness, they can also lead to cluster knowledge lock-in and path dependency [30], causing over-reliance on existing knowledge and lack of innovation motivation. Blockchain technology can effectively break this path dependency. Its decentralized and strongly open characteristics enable cluster knowledge network nodes to obtain knowledge transfer through multiple channels, and even use blockchain tokens to incentivize knowledge transfer interactions. Through reasonable token design, both senders and receivers of knowledge transfer can be rewarded, guiding nodes toward more effective knowledge transfer.

Trust is an indispensable factor in knowledge transfer research and has been proven to have significant positive effects on knowledge transfer between different subjects (including explicit and tacit knowledge) [31]. Trust is crucial for selecting cooperation partners and building cooperative relationships in industrial clusters [32]. Scholars have found that geographical proximity positively promotes knowledge transfer in industrial clusters [33], primarily because proximity enables real-time interaction, reduces cooperation uncertainty, and enhances mutual trust. Essentially, knowledge transfer in industrial clusters is also a cooperative relationship construction process, with efficiency directly limited by trust levels among knowledge network nodes. Regarding copyrights for knowledge transferred between different senders and receivers, blockchain's immutability and security provide uniquely advantageous protection, ensuring data authenticity, verifying the legitimacy of digital resources among network users, and even enabling contractual coordination between nodes to enhance trust, strengthen knowledge sharing motivation, and promote knowledge transfer.

3.4 Promoting Knowledge Application in Industrial Clusters through Blockchain Technology

Knowledge application, rather than knowledge itself, is the source of competitive advantage in industrial clusters. Knowledge network nodes must integrate external knowledge with their internal knowledge systems to broaden, extend, or reconstruct their knowledge architecture, optimizing knowledge stock or structure and thereby transforming new knowledge into services or products. However, phenomena often occur where nodes acquire and absorb knowledge but ultimately fail to apply it. Reasons include distrust of knowledge sources, uncertainty about application contexts, risk aversion regarding potential costs or opportunity costs [26], or limited organizational knowledge storage space leading to organizational forgetting of knowledge that cannot be promptly applied, resulting in knowledge attrition [34].

Blockchain's trustless characteristics, leveraging its traceability and immutability, can eliminate distrust of knowledge sources. Its distributed accounting and storage features enable all nodes to become knowledge uploaders, making the uploading of knowledge acquired from different task contexts—especially knowledge that may become organizational routines—less burdensome. This reduces knowledge application limitations caused by organizational boundaries, and blockchain's openness and transparency enable cluster knowledge network nodes to conveniently obtain background information when interpreting knowledge, enhancing risk awareness and improving the knowledge application environment.

4. Application Model of Blockchain Technology in the Knowledge Management Process of Industrial Clusters

Knowledge management in industrial clusters is a process involving multiple activities, levels, and knowledge network nodes. To enable effective knowledge sharing and application, blockchain technology can significantly promote knowledge management, as discussed above. Figure 3 [Figure 3: see original paper] presents the application model.

The model is supported by underlying technology, with main objects being knowledge network nodes: core enterprises, non-core enterprises, professional service providers, cluster knowledge innovation-oriented service providers, and government. When a knowledge network node establishes corresponding knowledge information on the blockchain platform and undergoes intellectual property certification (generating a block), other nodes can utilize this knowledge according to their development needs. During this process, the blockchain consensus mechanism performs identity authentication for all nodes to ensure secure knowledge sharing and application. Blockchain's technical characteristics solve trust issues among nodes and protect their knowledge rights, enabling full-process monitoring and ensuring equal rights for all knowledge network nodes.

The blockchain basic architecture mainly includes the data layer, network layer, consensus layer, smart contract layer, and application layer, as shown in Figure 4 [Figure 4: see original paper].

The **data layer** stores various types of intelligence information needed by knowledge network nodes, including intellectual property information, commodity circulation information, process innovation information, and policy guidance information. This knowledge is stored in a chain structure using timestamp technology to ensure blocks are connected chronologically, guaranteeing secure storage, immutability, and integrity.

The **network layer** ensures data propagation and verification among nodes through distributed networking, dynamically updating information from the data layer. It mainly involves asymmetric encryption transmission mechanisms, P2P networking mechanisms, and node authentication and data verification mechanisms.

The **consensus layer** ensures security and efficiency of information transmission among nodes during knowledge management by encapsulating consensus algorithms. It solves trust problems among distributed nodes, enabling them to reach consensus quickly for data updates and maintenance, which is key to decentralized knowledge network information storage. Consensus mechanisms mainly include PoA, RPCA, and PoS.

The **smart contract layer** enables the knowledge management network information collaboration platform to actively transmit and process relevant data by encapsulating various algorithm mechanisms and script codes to maintain normal platform operation. It mainly encapsulates node authentication management contracts, log recording contracts, intelligence collection contracts, and information collaborative sharing contracts.

The **application layer** encapsulates various application scenarios and cases for knowledge management within clusters, achieving on-chain and off-chain interaction of knowledge management data, as well as information query, process monitoring, data traceability, and resource integration through API interfaces.

5. Conclusion

Through the innovation and practice of blockchain technology, people increasingly realize that blockchain is not merely a technology but a transformation of thinking—a socialized "consensus trust" concept. As shown in Figure 2 [Figure 2: see original paper], each of the four basic processes of knowledge management in industrial clusters faces many different problems and dilemmas. Notably, trust issues are involved throughout, from knowledge creation to application. Industrial clusters are important economic support forms for nations, featuring complex knowledge network nodes, intricate knowledge flows, multiple knowledge behavior levels, uneven knowledge management status among nodes, and limited mutual trust. In most domestic industrial clusters, core enterprises play a dominant role in the knowledge network, representing a “centralized” state that hinders equal participation by other nodes. These factors lead to inefficient knowledge management. Blockchain’s technical characteristics can effectively solve these problems and promote knowledge management in industrial clusters. However, applying blockchain to knowledge management in industrial clusters is also constrained by other factors, such as relevant laws and regulations, institutional management, and feasible benefit distribution schemes.

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Note: Figure translations are in progress. See original paper for figures.