Scientific Research Publishing

iBusiness, 2023, 15, 209-235
https://www.scirp.org/journal/ib
ISSN Online: 2150-4083
ISSN Print: 2150-4075

The Development Status, Technical Characteristics, and Competitive Dynamics of Blockchain-critical Technologies in China and the USA: From a Patent Perspective

Bobo Zhang, Dongphil Chun*, Feng Yin, Yaoyao Guo

Graduate School of Management of Technology, Pukyong National University, Busan, Republic of Korea
Email: *performance@pknu.ac.kr, zhangbobo00@pukyong.ac.kr, yinfeng2021@pukyong.ac.kr, guoyaoyao@pukyong.ac.kr

How to cite this paper: Zhang, B.B., Chun, D., Yin, F. and Guo, Y.Y. (2023). The Development Status, Technical Characteristics, and Competitive Dynamics of Blockchain-critical Technologies in China and the USA: From a Patent Perspective. *iBusiness, 15,* 209-235.
https://doi.org/10.4236/ib.2023.154016

Received: October 12, 2023
Accepted: December 9, 2023
Published: December 12, 2023

Abstract

As an emerging technology, blockchain has attracted significant attention from countries worldwide. Based on patent measurement analysis methods, this paper conducts an in-depth study of invention patents related to crucial blockchain technologies in China and the United States from 2016 to 2022. The study found that the overall trend of the number of patents first increases and then declines, and the layout of the USA in this field is earlier than that of China, but the total number of patents in China exceeds that of the USA; the number of Chinese invention patents located in the core area of the international patent classification (IPC) large group exceeds that of the USA, and there are differences in the types of active technologies between China and the USA; the technology life cycle of China and the USA in this field as a whole has entered the declining period, but segmented technology areas such as privacy protection and cross-chain technology are still in the growth period.

Keywords

Blockchain-critical Technologies, Patentometrics, Invention Patents, Technology Life Cycle

1. Introduction

Blockchain technology originated from Bitcoin and has features such as decentralization, immutability, collective maintenance, security, and trustworthiness (Yaga et al., 2019). In recent years, the rapid development of blockchain technology has been widely recognized globally, and it has been used in e-commerce

(Ismanto et al., 2019), finance (Chen & Bellavitis, 2020), supply chain (Liu & Li, 2020; Mattke et al., 2019), education (Sharples & Domingue, 2016), e-government (Batubara et al., 2018), and other areas with a large number of applications. In particular, the USA and China lead the development and innovation of next-generation information technology and have been committed to blockchain technology research and development, application promotion, and standards development, and continue to promote the development of blockchain technology. In the USA, the Department of Homeland Security actively explores the application of blockchain, integrating blockchain into the systems of agencies such as the USA Customs Border Protection, Citizen Immigration Services, and the Transportation Security Administration. The Department of Defense experiments with blockchain-based cybersecurity protection (Asuncion et al., 2021). NASA engineers propose an aviation blockchain infrastructure and launch research on applications in related areas (Reisman, 2019). In China, blockchain-based system platforms led by government departments and built jointly with several companies are officially online (Cai et al., 2021; Sigley & Powell, 2023), such as the "Central Bank Trade Finance Blockchain Platform" of the People's Bank of China and the Blockchain Service Network of the National Information Center.

As an emerging technology, the core of blockchain's competitiveness relies on critical technological innovation. Invention patents reflect the latest technological advances and are the direct outputs of technological innovation, which can be an essential indicator of a country's R&D capability. Patent data contain valuable information such as inventors, international patent classification (IPC), and countries (Ernst, 2003). Therefore, classifying and analyzing patent information can explain current technological developments, technical cooperation, and industrial competition. However, some blockchain-based academic issues require further study. For example, what are the trends in the field in China and the USA concerning rapid iterative updates of blockchain technology? What are the life cycle and technical cooperation characteristics of critical blockchain technologies in China and the USA? This study attempts to answer these questions using a potentiometric approach.

There is substantial literature on blockchain patents, and some scholars have studied the dynamics of technological competition between China and the USA based on blockchain patents. Denter used the number of global blockchain patent applications as an indicator and found that Asian countries drive blockchain inventions (Denter, 2021). Jiang used patent analysis to compare the development of blockchain technology in China and the USA and found that the technology trends are the same (Jiang et al., 2021). Ozcan found that China and the USA have the potential to influence the future development of blockchain technology (Ozcan & Unalan, 2020). Nan compared blockchain technology development and technical cooperation between the USA and China based on patent data (Nan et al., 2022).

In conclusion, these studies focus more on the macro-level comparison of blockchain technologies between China and the USA. Further in-depth research on the development, trends, and competition of critical technologies is required. Therefore, this study adopts a potentiometric approach based on blockchain patent data from China and the USA to further reveal the development and competition situation of blockchain-critical technologies in China and the USA and provide a reference for stakeholders.

The rest of the paper is organized as follows. Section 2 describes the literature related to blockchain and patentometrics. Section 3 presents our research design and data. Section 4 presents the findings and analyzes the discussion. Chapter 5 presents the conclusions, limitations, and future research directions.

2. Literature Review

2.1. Blockchain-critical Technologies

In general, critical technologies have the characteristics of being hidden knowledge-intensive, and it is difficult to break through the barriers of related technologies by copying and imitation (Norman, 2002; Prahalad & Mashelkar, 2010). How to conquer critical technologies is a critical path for the development of science and technology innovation. After the accumulation of technological and knowledge innovation capabilities, countries have made significant achievements in critical blockchain technologies.

The related literature defines an infrastructure model for blockchain technology (Saghiri, 2020; Syed et al., 2019; Xu et al., 2017; Yuan & Wang, 2018; Zheng et al., 2017), which mainly consists of the network, data, consensus, contract, and application layers. The critical technologies contained in each layer are as follows.

The network layer is mainly a mechanism for implementing distributed networks through networking, such as P2P (Delgado-Segura et al., 2018; Wang et al., 2021), designing specific data validation mechanisms, and information dissemination protocols that enable every node to participate in data validation and bookkeeping. This process involves technical elements such as network communication, data storage, and big data.

The data layer provides a shareable data ledger for each node of the decentralized system (Kakavand et al., 2017; Natarajan et al., 2017). When the system performs a transaction, the transaction data and encoding are assembled into a time-stamped data block in a block linked to the current longest main blockchain to form a new block of data. This process involves technical elements, such as hashing algorithms, Merkel trees, timestamps, data blocks, and chain structures.

The consensus layer mainly involves a consensus mechanism, which enables efficient consensus on the correctness of block data in a decentralized system with highly decentralized decision-making and is the governance mechanism of blockchain. This process is mainly the consensus mechanism algorithm (Bains, 2022; Lashkari & Musilek, 2021) and one of the critical technologies of blockchain, including proof of work, proof of stake, delegated proof of stake, and Practical Byzantine Fault Tolerance.

The contract layer is a variety of script codes encapsulated in the blockchain, which can be custom-designed according to the application scenario and is the basis for implementing blockchain programmability, which can be executed automatically without any intermediary according to the constraints in the code (Cong & He, 2019; Khan et al., 2021). This process involves system environment support for the contract and the technical elements of contract development, deployment, revocation, and detection.

The application layer is the showcase layer of the blockchain and includes various application scenarios and cases. This process contains various technical elements, such as data storage, which makes the migration of business systems to the chain generally adopt a two-layer design owing to scalability and other issues, such as supporting data storage on and off-chain and coordinating the correspondence in smart contracts (Benisi et al., 2020; Cangir et al., 2021). Meanwhile, with the growing richness of application scenarios, cross-chain technology addresses the need for interconnections between individual blockchains to achieve secure and efficient value flow and business collaboration between different blockchains (Lin et al., 2021; Pillai et al., 2020).

At present, there is a typical blockchain network performance that cannot meet large-scale application landings to effectively improve throughput while ensuring system security. The leading solutions include on-chain and off-chain expansion (Liu et al., 2022; Wang et al., 2020).

2.2. Blockchain Patents Analysis

In recent years, blockchain patents have become a research hotspot. Relevant research using patent data covers a wide range of areas, including technological trends, industrial applications, and industry performance.

For example, Hu used basic patent statistics to identify the underlying technologies that makeup blockchain technology (Hu et al., 2021). Bamakan used text mining and patent analysis to map current trends in blockchain technology (Bamakan et al., 2021). Daim used patent analysis to understand how blockchain and the Internet of Things converge (Daim et al., 2020). Dehghani interviewed vital players in a patent filing to study the trends of blockchain technology patent filing and filing strategies (Dehghani et al., 2021). Yang analyzed USA blockchain patents to obtain an overview of recent blockchain technology developments (Yang & Hwang, 2020). Zanella proposed an unsupervised system patent analysis framework to explore trends in blockchain application areas (Zanella et al., 2023). Huang used patent analysis techniques to explore the developmental trends of blockchain technology in energy systems (Huang et al., 2020). Zhang used the latent Dirichlet allocation topic model to analyze blockchain patents, describe the current status of technology development, and predict future development trends (Zhang et al., 2021). Li conducted a primary path analysis of patents to identify the development trajectory of the blockchain (Li & Li, 2022). Massaro examined relevant papers and patents to provide data on blockchain implementation expectations in the healthcare industry (Massaro, 2021). Filippova empirically analyzed blockchain by using the latest available blockchain-related patent data to propose that blockchain has emerged as a general-purpose technology (Filippova, 2019). Someda combined patent and input-output analyses for knowledge spillover modeling (Someda et al., 2022).

2.3. Research Methods

Patentometrics evolved from bibliometrics, and Bibliometrics is one of the essential research contents of information science (Broadus, 1987). Because patentometrics has similarities with bibliometrics, some analytical methods and tools in bibliometrics have been introduced into patentometrics. In 1994, Narin first introduced the concept of patent metrology (Narin, 1994). With the intensification of global competition in science and technology, patent information measurement research has received increasing attention from scholars, companies, and governments, and its applications have become more widespread. The related research is expanding (Narin, 1995; Verbeek et al., 2002). Generally, patents can be used as a typical representation of technology (Trajtenberg et al., 1997). Patent measurement methods are used to measure the state of technological innovation in a certain period, understand industry trends, and distinguish the strengths of competitors. They have become a popular research topic in related fields (Lin, 2008). Scholars have used patent data to analyze current and future technology trends (Archibugi & Planta, 1996; Basberg, 1987). Despite these shortcomings, patent data are often used as indicators of innovation activity (Griliches, 1998).

Patent analysis helps organizations determine the novelty of their inventions and their competitors' intellectual property and technological competitiveness (Abraham & Moitra, 2001). However, regarding patent analysis techniques, extensive literature has used visualization and text-mining-based approaches to analyze patent content (Abbas et al., 2014).

Text mining derives valuable information from natural language through patent analysis tools and is primarily based on rule-based, property-function-based, NLP, and neural network-based approaches. For example, Arts developed natural language processing techniques to determine the creation and impact of new technologies in the USA patent community (Arts et al., 2021). To screen the ICTC patent corpus accurately, Wu used deep learning and NLP techniques to automatically identify whether patents are related to building information and communication technologies (Wu et al., 2020). Trappey developed a patent recommender based on NLP to discover semantically related patents for technology mining and trend analysis (Trappey et al., 2021). Chen used artificial neural network techniques to explore the impact of patent metrics on the market value of American pharmaceutical companies (Chen & Chang, 2009). Abdelgawad improved the patent classification accuracy based on neural networks (Abdelgawad et al., 2020), and Yoon proposed an attribute function-based patent network for technology trend analysis (Yoon & Kim, 2012).

Another approach to patent analysis is to use visual tools to represent patent information and result analysis, typically using patent networks or clustering methods. For example, Dolfsma used social network analysis to map patent co-classifications and indicated innovation system characteristics (Dolfsma & Leydesdorff, 2011). Zheng used patent network analysis to examine the development of international cooperation in nanotechnology (Zheng et al., 2014). Fuzzy clustering uses data to discover potential themes and technologies (Jang et al., 2021). Altuntas proposed a clustering method based on patent information to evaluate emerging candidate technologies (Altuntas et al., 2020). Yu identified the development trajectory of blockchains based on a master path analysis (Yu & Pan, 2021).

The existing literature has researched key blockchain technologies and patent analysis. The novelty of this article lies in 1) research content. Based on the seven critical technologies of blockchain, the development trend of key blockchain technologies in China and the United States is analyzed from the technical characteristics, life cycle, and other dimensions, which helps to reveal the competitive situation of China's blockchain technology systematically. 2) Research perspective. From the perspective of technological heterogeneity, considering regional differences, the critical blockchain technologies of China and the United States are used as research objects to distinguish the technological heterogeneity of the two countries.

3. Research Design and Data

3.1. Research Design

In this study, we analyze the current development status, technical features, and competitive dynamics of blockchain-critical technologies in China and the USA using potentiometric methods in the following process. First, by searching the blockchain technology-related literature, blockchain-critical technology options are proposed, and blockchain industry experts are consulted to determine the final technology. Second, the search method and patent database are determined to collect invention patent data using blockchain-critical technology and complete data collection. Third, the number of patents is counted and compared based on a time series to analyze the current situation of blockchain-critical technology development. Fourth, we analyzed the active fields and technical cooperation of blockchain-critical technologies based on the number of patents cited and patent owners. Fifth, we further analyze the technical composition of blockchain-critical technologies and detail the life cycle characteristics of each technology.

Gephi is an analysis software tool for social networks, and this study uses Gephi to construct a technical cooperation network graph for patent owners.

3.2. Data Sources

Based on the above research, this study uses blockchain-critical technologies as an example to start the research and screen out some blockchain-critical technologies, namely consensus mechanism, smart contract, data storage, privacy protection, expansion technology, cross-chain technology, and peer-to-peer networks.

The data in this paper comes from the Derwent patent database, which contains patent documents from more than 100 countries and regions around the world. Combined with the suggestions of experts in the field of blockchain technology, the patent search expression was finally determined after several pre-search tests (as shown in Table 1), and the search time was set to 20160101-20221230. To improve the accuracy of the patent search, patent filtering conditions were also set to USA invention patents and Chinese invention patents.

The search data were obtained and summarized using Excel and then de-duplicated, cleaned, and merged. A total of 10,833 patents were filed, including

Table 1. Patent search expressions.

Technology Type	Search statements
Consensus mechanism	(TI = ("consensus" or "pow" or "bft" or "pos")) and (TI = ("blockchain" or "ledger" or "alliance chain" or "public chain"))
Smart Contracts	(TI = ("smart contract" or "contract")) and (TI = ("blockchain" or "ledger" or "alliance chain" or "public chain"))
Data Storage	(TI = ("distributed storage" or "data storage" or "secure storage")) and (TI = ("blockchain" or "ledger" or "alliance chain or public chain"))
Privacy Protection	(TI = ("privacy" or "data security" or "data protection")) and (TI = ("blockchain" or "ledger" or "alliance chain" or "public chain"))
Expansion Technologies	(TI = ("sharding" or "lightning network" or "raiden network" or "segregated Witness")) and (TI = ("blockchain" or "ledger" or "alliance chain" or "public chain"))
Peer-to-Peer Networks	(TI = ("network" or "peer to peer" or "p2p")) and (TI = ("blockchain" or "ledger" or "alliance chain" or "public chain"))
Cross-chain technology	(TI = ("cross-chain" or "atomic swap" or "tary schemes" or "side chain" or "relays" or "Hashed Time LockContract" or "HTLC")) and (TI = ("blockchain" or "ledger" or "alliance chain" or "public chain"))

2629 American and 8204 Chinese patent applications.

4. Results and Discussions

4.1. Blockchain-Critical Technology Development Status Analysis

4.1.1. Analysis of Patent Applications for Inventions

According to the statistical method of priority countries or regions, a chart of the number of blockchain-critical technology patent applications between China and the USA is shown in Figure 1. In 2016, the number of patent applications in China was less than 10, but it reached more than 2000 in 2021. The number of patent applications in the United States was only more than 50 in 2016 and reached the highest value in 2019, but it was less than 500. From 2016 to 2017, the total number of patent applications between the two countries was relatively small, and the USA was ahead of China. In 2018, the total number of patent applications between the two countries increased significantly, and the number of Chinese patent applications exceeded that of the USA. From 2019 to 2020, the number of patent applications in China will increase at a faster rate, showing an "exponential" explosive growth, while the USA shows the opposite trend, with the number of patent applications slowly decreasing. From 2021 to 2022, the number of patent applications in both countries decreased significantly, showing a downward trend.

According to the patent application timeline sequence, the number of USA patent applications peaks in 2019 and decreases annually, and the number of Chinese patent applications increases at a significant rate and starts to decline in 2022. The number of Chinese patent applications in 2021 is approximately seven times that of USA applications.

4.1.2. Analysis of Invention Patents Granted

The trend in the number of blockchain-critical technology patents granted in China and the USA corresponds to the trend in the number of patent applications,

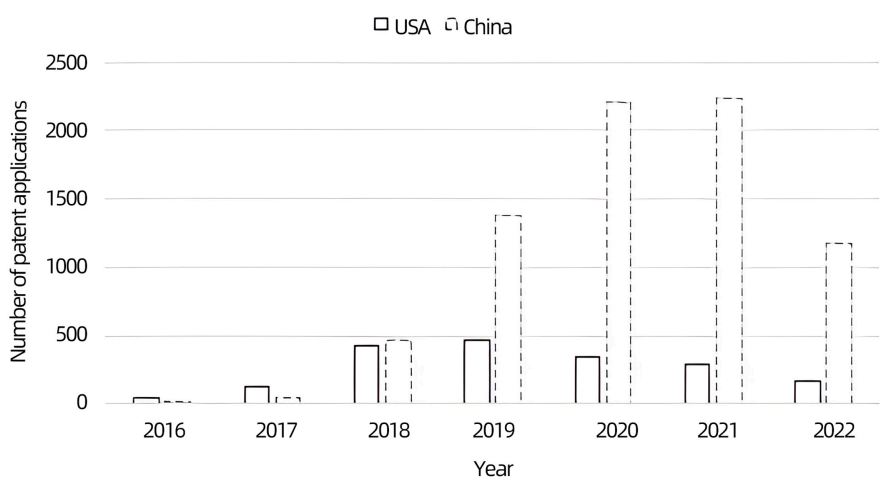

Figure 1. The number of patent applications for blockchain-critical technologies in China and the USA.

as shown in Figure 2. In 2016, the number of patent authorizations in China was only 11, but it reached more than 800 in 2020. The lowest number of patent authorizations in the United States was 17 in 2022, and reached the highest in 2019, with more than 300 patents. The number of patents granted from 2016 to 2017 was relatively small. However, the USA exceeded China in terms of quantity. Between 2018 and 2019, the number of patents granted started to increase significantly, among which the number of USA grants peaked in 2019, and the growth rate of the number of Chinese grants exceeded that of the USA. From 2020 to 2022, the number of USA patents granted decreased year by year, showing a downward trend, while the number of Chinese grants peaked in 2020 and then decreased year by year.

4.1.3. Analysis of PCT Patent Applications

Patent Cooperation Treaty (PCT) patent applications reflect the strength of a country's innovation body in participating in international competition. As seen in Figure 3, in 2016 and 2022, the number of PCTs in China was 0, reaching the highest value in 2020, close to 300, while the highest value in the United States

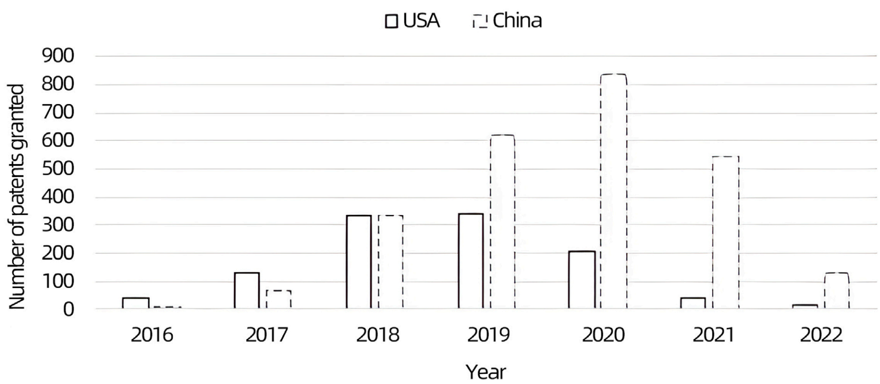

Figure 2. The number of patents granted for blockchain-critical technologies in China and the USA.

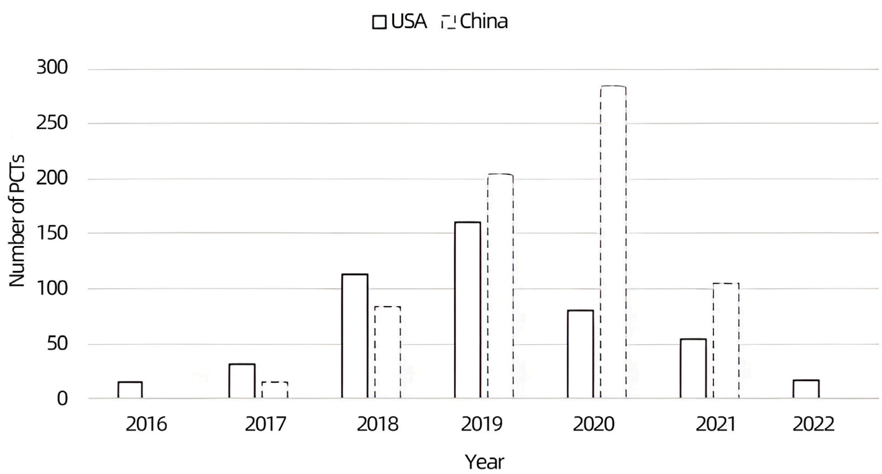

Figure 3. The number of PCT patents for blockchain-critical technologies in China and the USA.

was only 160. From the number of PCT international patent applications, the number of PCT patent applications in China and the USA maintained steady growth from 2016 to 2018, and the number of PCT patent applications in the USA exceeded the number of PCT patent applications in China. In 2019, the number of PCT patent applications in China exceeded the number of PCT patent applications in the USA for the first time, while the number of PCT patent applications in the USA reached its peak; from 2020 to 2022, the number of PCT patent applications in the USA decreased year by year, and the number of PCT patent applications in China reached its peak in 2020, after which it showed a rapidly decreasing trend.

From 2009 to 2017, blockchain projects such as Bitcoin, Ethereum, Hyperledger, and Ripple flourished in the USA, and blockchain applications were extended to multiple application areas. From the trend of the number of invention patent applications, patent grants, and PCTs, the USA's layout in blockchain-critical technology areas is earlier than China's and is a vital force leading to global blockchain development. Regarding policy, the United States government departments have continued to strengthen forward-looking technology research. The United States Congress, the Department of Commerce's National Institute of Standards and Technology (NIST), and other departments have released reports such as the 2018 Joint Economic Report, Blockchain: Background and Policy Issues, Blockchain and Applicability in Government Applications, and Blockchain Technology Overview. In July 2019, the United States Congress approved the Blockchain Promotion Act, which requires the establishment of a blockchain working group at the federal government level to promote the harmonization of blockchain technology definitions and standards.

The Chinese government attaches great importance to blockchain development and has implemented a series of measures. In December 2016, the State Council of China released the "13th Five-Year Plan for National Informatization," which included blockchain technology in its national informatization plan for the first time. Various industries highly value the development of blockchain technology, and the national government continues to strengthen its support of the blockchain industry. For example, China's State Council, the People's Bank of China, the Ministry of Industrial Information, and other departments have released documents such as the "14th Five-Year Plan for the Development of the Digital Economy," the "13th Five-Year Plan for the Development of Financial Information Technology in China" and the "2018 White Paper on the Development of China's Blockchain Industry." During this period, Chinese technology companies actively laid out blockchain-critical technologies and applications, such as the Tencent Cloud Blockchain Service Platform (TBaaS) launched by the Tencent and Antchain (ANTCHAIN) by the Ant Group.

4.2. Analysis of Typical Institutions and Cited Patents

4.2.1. Analysis of Highly Cited Patents

Research shows that highly cited patents are considered core patents with solid innovation and high value in a particular technology field (Harhoff et al., 1999). The patent citation process involves knowledge generation, dissemination, development, and reorganization.

The basic information of the top five cited patents of blockchain-critical technologies in China and the USA are listed according to technology type, as shown in **Table 2** and **Table 3**. Among them, according to the number of cited frequencies, it is found that the top five are all Chinese patents, and among the top ten cited patents, China accounts for six, and the USA accounts for four.

Among the patents cited for blockchain-critical technologies in China, the patent with the highest frequency of 127 citations is related to cross-chain technology developed by BUBI BEIJING NETWORK TECHNOLOGY CO LTD. In general, the number of cited patents in the field of blockchain consensus and network technology is high, indicating that there are also more core patents and high-value patents in this field, while the corresponding average frequency of citations for the expansion technology is the lowest, and the highest value is only six times. In addition to cross-chain technology-related enterprises actively laying out PCT patents to seize the international market, fewer PCT patents have been applied in other technology fields.

The most frequently cited patent, with 56 citations among the critical technologies of blockchain in the USA, is patents related to blockchain network technology developed by CISCO TECHNOLOGY Inc. Among them, patents in the blockchain network and smart contract technology field are cited more often, while the number of patents with citation frequency corresponding to the expansion technology is only 1. There were three citations is 3. In addition to enterprises related to cross-chain technology and expansion technology, which mainly layout domestic patents, enterprises in other technology fields actively layout PCT patents and continuously expand their influence in the international market.

To further investigate the active areas of blockchain-critical technologies, the well-known Price's law (Price, 1986) in bibliometrics is used to determine the minimum number of citations of patents applied for by the patentee using its formula $m_p = 0.749 \times \sqrt{N_{p\max}}$ to derive the type of active technologies, where is the maximum number of citations of the patent. The value of $N_{p\max}$ in China is calculated to be 128, $m_p = 8.474$, and Chinese patent owners whose patents are cited more frequently than nine are selected as active patent owners; the value of $N_{p\max}$ in the USA is calculated to be 56, $m_p = 5.605$, and Chinese patent owners whose patents are cited more frequently than six are selected as active patent owners.

Statistics on the number of active patent owners reveal that blockchain-critical technologies in China have a large number of active patent owners in the areas of blockchain consensus, smart contracts, privacy protection, data storage, blockchain networks, and cross-chain technologies, which also indicates that innovation activities are more active in these technologies. Similarly, blockchain-critical technologies in the USA have more active innovation activities in blockchain

Table 2. Cited frequency of Chinese blockchain-critical technology patents.

Technology type	Patent code	Whether PCT	First patent owner	Cited frequency
Consensus mechanism	CN106878000	NO	BEIJING SMART CARD TECHNOLOGY RES INST	73
	CN107733855	NO	CAS INFORMATION ENG INST	57
	CN107767926	NO	CHINA UNICOM GROUP CO LTD	41
	CN108616596	NO	UNIV NANJING POST & TELECOM	32
	CN109639753	NO	ZHONGAN INFORMATION TECHNOLOGY SERVICE	19
Smart Contracts	CN107992621	NO	HANGZHOU YUNXIANG NETWORK TECHNOLOGY CO LTD	31
	CN109190410	NO	UNIV HUAZHONG SCI & TECHNOLOGY	30
	CN110392052	NO	IND & COMML BANK CHINA LTD	25
	CN108768607	NO	ZHONGCHAO CREDIT CARD IND DEV CO LTD	24
	CN109451467	NO	UNIV JIANGXI SCI & TECHNOLOGY	23
Privacy Protection	CN109741803	NO	UNIV NANJING	35
	CN109451467	NO	UNIV JIANGXI SCI & TECHNOLOGY	23
	CN109559117	NO	UNIV BEIJING SCI & TECHNOLOGY	20
	CN109255251	NO	ANHUI ZHONGKE ZHILIAN INFORMATION TECHNO	18
	CN111047450	YES	ALIPAY HANGZHOU INFORMATION TECHNOLOGY	17
Data Storage	CN109639406	NO	GUOTAI JUNAN SECURITIES CO LTD	24
	CN109165190	NO	UNIV NANJING POST & TELECOM	18
	CN107958412	NO	YUNNAN FEIWANG TECHNOLOGY CO LTD	18
	CN109299217	NO	FU A	16
	CN109191108	NO	GUANGDONG BLUEBEE INFORMATION TECHNOLOGY	16
Peer-to-Peer Networks	CN107181765	NO	GUANGZAIWUXIAN BEIJING TECHNOLOGY CO LTD	65
	CN108230109	NO	LUO M	57
	CN109741803	NO	UNIV NANJING	35
	CN108616596	NO	UNIV NANJING POST & TELECOM	32
	CN109302405	NO	UNIV BEIJING POST & TELECOM	29
Expansion Technologies	CN111680050	NO	HANGZHOU HYPERCHAIN TECHNOLOGY CO LTD	6
	CN111294234	NO	MAIKESI SUZHOU DATA TECHNOLOGY CO LTD	6
	CN112260836	NO	UNIV CHINA ELECTRONIC SCI & TECHNOLOGY	5
	CN111127017	YES	SICHUAN INTERSTELLAR ROEWE TECHNOLOGY CO LTD	5
	CN111309801	NO	AISINO CORP	2
Cross-chain technology	CN105488675	NO	BUBI BEIJING NETWORK TECHNOLOGY CO LTD	127
	CN107301600	YES	BEIJING TIANDE TECHNOLOGY CO LTD	38
	CN112200682	YES	TENCENT TECHNOLOGY SHENZHEN CO LTD	13
	CN111181968	YES	BEIJING KSYUN NETWORK TECHNOLOGY CO LTD	12
	CN109934592	YES	SHENZHEN WANGXIN TECHNOLOGY CO LTD	11

Table 3. Cited frequency of the USA blockchain-critical technology patents.

Technology type	Patent code	Whether PCT	First patent owner	Cited frequency
Consensus mechanism	US2019238525	YES	SALESFORCE.COM INC	28
	US2017103468	YES	TRANSACTIVE GRID INC	19
	US2017344987	YES	MASTERCARD INT INC	18
	US2018123882	NO	INT BUSINESS MACHINES CORP	16
	US2018101560	NO	INT BUSINESS MACHINES CORP	9
Smart Contracts	US10135607	YES	DRAGONCHAIN INC	43
	US2018117447	NO	TRAN B	31
	US2018117446	NO	TRAN B	30
	US2017300872	YES	R3 LTD	26
	US10298395	YES	ACCENTURE GLOBAL SOLUTIONS LTD	24
Privacy Protection	US2017289111	YES	MORGAN CHASE BANK J P	16
	US2019238311	YES	ALIBABA GROUP HOLDING LTD	9
	US10382205	YES	KO H	8
	US10797885	NO	WELLS FARGO BANK NA	4
	US2018307854	NO	SAP SE	3
Data Storage	US2018219669	NO	HEWLETT PACKARD ENTERPRISE DEV LP	12
	US2019245688	YES	SQUARELINK INC	5
	US2019130114	YES	PRICEWATERHOUSECOOPERS LLP	5
	US2019268141	YES	SAMSUNG ELECTRONICS CO LTD	4
	US10965448	NO	UNIV ILLINOIS FOUND	3
Peer-to-Peer Networks	US10299128	YES	CISCO TECHNOLOGY INC	56
	US2017011460	YES	OUISA LLC	45
	US10833843	NO	UNITED SERVICES AUTOMOBILE ASSOC USAA	44
	US10250708	YES	AKAMAI TECHNOLOGIES INC	39
	US10872381	NO	STATE FARM MUTUAL AUTOMOBILE INSURANCE	32
Expansion Technologies	US2020013026	YES	GMO GLOBALSIGN INC	3
	——			
	——			
	——			
	——			
Cross-chain technology	US2019358515	NO	TRAN B	7
	US10805090	NO	BLOCKSTREAM CORP	5
	US11310060	NO	BLOCKSTREAM CORP	3
	US2019340267	NO	INT BUSINESS MACHINES CORP	2
	US2019266612	YES	WALMART APOLLO LLC	1

consensus, smart contracts, and blockchain networks.

4.2.2. Analysis of Typical Institutional Patent Owners

The data relating to patent owners were screened according to the patent applications of blockchain-critical technologies in China and the USA, and the top 10 patent owners were counted, as shown in Table 4.

The top five blockchain critical technology patent owners in China are Tencent technology shenzhen co. ltd., Alipay hangzhou information technology, Ant blockchain technology shanghai co, China united network communications corp, Ind & comml bank china ltd. among them, Tencent technology shenzhen co ltd and Alipay hangzhou information technology are lead to the number of patent applications.

The top five blockchain critical technology patent owners in the USA are Int business machines corp, State farm mutual automobile insurance, Mastercard int inc, Hewlett packard enterprise dev lp, and Bank of america corp. the number of patent applications for Int business machines corp is 282, in contrast to other companies. Tencent technology shenzhen co ltd, Alipay hangzhou information technology, and Int business machines corp are internationally renowned high-tech enterprises with strong innovation abilities and obvious technical advantages. Overall, Chinese patent owners filed more patent applications

Table 4. The number of top 10 patent owners in the USA and China.

China		USA	
Patent owner	Quantity	Patent owner	Quantity
TENCENT TECHNOLOGY SHENZHEN CO LTD (TNCT-C)	336	INT BUSINESS MACHINES CORP (IBMC-C)	282
ALIPAY HANGZHOU INFORMATION TECHNOLOGY (ALPY-C)	316	STATE FARM MUTUAL AUTOMOBILE INSURANCE (STFA-C)	46
ANT BLOCKCHAIN TECHNOLOGY SHANGHAI CO (ALPY-C)	159	MASTERCARD INT INC (MSTC-C)	42
CHINA UNITED NETWORK COMMUNICATIONS CORP (CUNC-C)	122	HEWLETT PACKARD ENTERPRISE DEV LP (HEWP-C)	30
IND & COMML BANK CHINA LTD (ICBC-C)	104	BANK OF AMERICA CORP (BAMC-C)	30
ADVANCED NEW TECHNOLOGIES CO LTD (ALPY-C)	90	CAPITAL ONE SERVICES LLC (CPTL-C)	23
BEIJING AIMORUICE TECHNOLOGY CO LTD (BEIJ-Non-standard)	84	MICROSOFT TECHNOLOGY LICENSING LLC (MICT-C)	21
ALIBABA GROUP HOLDING LTD (ABAB-C)	83	SALESFORCE.COM INC (SAFO-C)	21
HANGZHOU HYPERCHAIN TECHNOLOGY CO LTD (HANG-Non-standard)	80	MADISETTI V (MADI-Individual)	20
STATE GRID CORP CHINA (SGCC-C)	79	CISCO TECHNOLOGY INC (CISC-C)	18

than USA patent owners in blockchain-critical technologies. Thus, they have many patent applications and have created a comprehensive patent layout in the blockchain field.

To further analyze the cooperation of the patent owners, the data of the patent owners were first organized, the co-occurrence matrix was generated, and then the matrix data were imported into the Gephi software to draw the cooperation network diagram of the patent owners. This is shown in Figure 4 and Figure 5.

The density of the cooperative network of USA patent owners was 0.006. There are many small groups in the form of independent binary and triadic groups, and the overall network structure is loose. Based on the PageRank algorithm to measure the influence of patent owners, the PR value of the top 10 ranked patents ranged from 0.0071 to 0.0038, and the influence of patent owners was relatively small. Among them, the top four patent owners are Hewlett packard enterprise dev lp (HEWP-C), Visa int service assoc (VISS-C), Int business machines corp (IBMC-C), and Eygs llp (EYGS-Non-standard), with PR values of 0.0071, 0.0063, 0.0059, and 0.0056, respectively, indicating that these four patent owners have a more significant influence on the entire network and form four large-scale sub-networks centered on them. At the same time, cooperation between patent owners involves different types of institutions, such as individual-individual

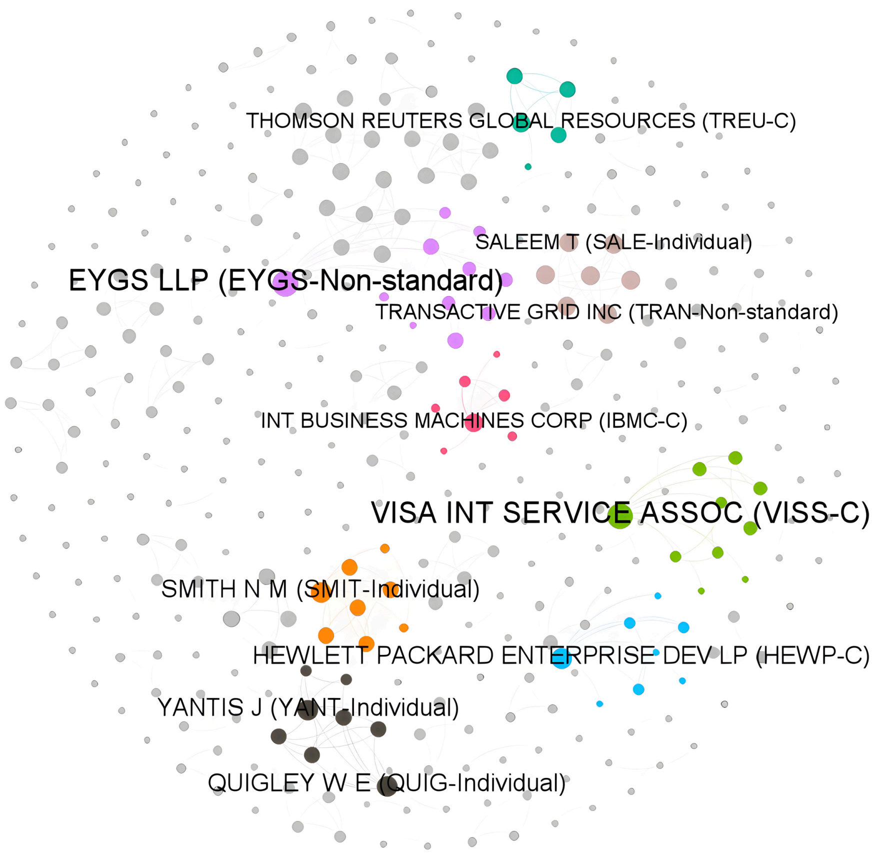

Figure 4. Cooperation network map of patent owners of blockchain-critical technologies in the USA.

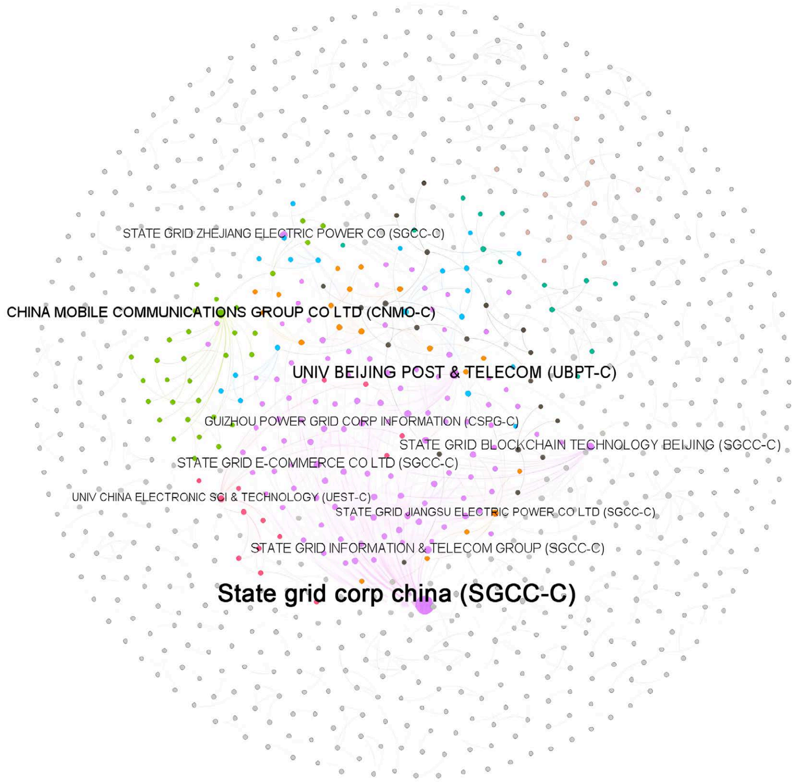

Figure 5. Cooperation network map of patent owners of blockchain-critical technologies in China.

and corporate-corporate.

The density of the cooperative network of Chinese patent owners is calculated to be only 0.002, with an average degree of 2.2, indicating that the network structure is relatively loose, and a large number of small groups are not connected. Based on the PageRank algorithm to calculate the influence of patent owners, the top three patent owners are State grid corp china (SGCC-C), Univ beijing post & telecom (UBPT-C), and China mobile communications group co ltd (CNMO-C), with PR values of 0.0159, 0.0083, and 0.0066, respectively. Patent owners dominate the entire network and form small groups. In particular, the STATE GRID CORP CHINA (SGCC-C) forms a larger-scale sub-network with a strong influence centered on it, but most of the members in its dominant group are affiliated companies. In addition, there are different types of institutions among network partners, such as universities, enterprises, and enterprises. The characteristics of an industry-university-research combination are more pronounced, which helps knowledge flow and industrial development.

4.3. Blockchain-Critical Technology Lifecycle Characteristics Analysis

4.3.1. Analysis of Technical Composition

Based on the IPC established by the Strasbourg Agreement on International Patent Classification, the patents are divided into eight divisions (A-H) according to the technical fields to which they belong, and the patents related to blockchain-critical technologies are mainly distributed in two divisions: G-Physical and H-Electrical. Therefore, the technical layout of the two countries in this field can be explored by analyzing the IPC classification of blockchain-critical technologies in China and the USA. According to the statistics of the top six patent applications of blockchain-critical technologies in China and the USA by the IPC large group, the most laid out category in China is G06F-021, with 2366 patents, while the most laid out category in the USA is H04L-009, with 1284 patents. The most significant number of patents in the USA was H04L-009, with 1284 patents. The details are presented in Table 5.

From the IPC large group statistics, China and the USA filed more invention patents in cyber security, data privacy, secure communication, etc. This shows that both countries are continuously strengthening basic research and original innovation in this field, especially by conducting in-depth research on critical technologies and reflecting the importance of privacy and security in blockchain technology. In China, the third highest number of patent applications is for critical technologies related to financial and other applications, such as smart contracts. At the same time, the USA has relatively few patents laid out in applications, with only 264 patents. In general, China's layout of blockchain-critical technologies involves theory and application, and the USA is more inclined toward theory.

To further analyze the cross-IPC combination of patents in this field, we first compiled the IPC large group data of invention patents and generated the co-occurrence matrix. We then imported the matrix data into Ucinet software

Table 5. IPC of blockchain-critical technologies in China and the USA.

IPC Large Group	Technology Field	USA	China
G06Q-020	Payment structures, schemes or protocols, including the processes by which payments can be made between merchants, banks, users and sometimes between third parties	815	1254
G06F-016	Information retrieval; database structure; file system structure	608	2045
G06F-021	Security devices to protect the computer, its components, programs or data from unauthorized acts	456	2366
H04L-009	Confidential or secure communication devices; network security protocols	1284	1514
H04L-029	Devices, equipment, circuits and systems not included in individual groups H04L1/00 to H04L27/00	647	1636
G06Q-040	Finance; Insurance; Tax Strategy	264	1862

and selected the Core-Periphery structural model for numerical calculation. Assuming that the Coreness score is greater than 0.1 for the core area, there are ten IPC large groups of Chinese invention patents located in the core area. Including: G06F-021, G06F-016, H04L-009, H04L-029, G06Q-040, G06Q-020, H04L-067, G06Q-030, G06Q-050, G06Q-010, with the maximum Coreness value of 0.527. There are six large IPC groups of USA invention patents located in the core area, including H04L-009, G06Q-020, G06F-016, H04L-029, G06F-021, G06Q-040, and with a maximum coreness value of 0.695. The number of Chinese invention patents located in the core exceeds that in the USA, but the top six IPCs are ranked in the same large group.

4.3.2. Technology Life Cycle Analysis

The technology life cycle diagram method, also known as the reverse S-curve, reflects the number of patents and patent applicants in a certain period. The number of patents reflects the output of blockchain technology, and the number of patent applicants reflects the number of entities involved in scientific and technological activities. The relationship between the two can be used to determine the maturity of the technology field. In general, the technological life cycle is divided into five stages: germination, growth, maturity, decline, and recovery.

The development history of critical blockchain technologies in the USA is shown in Figure 6. After 2016, blockchain-critical technologies entered a rapid growth period, and the number of patent applications grew significantly. From 2018 to 2019, the technology entered a maturity period and the number of patent applicants grew slightly. After 2019, the number of patents and patent applicants declined significantly, and technology entered a declining period.

The development history of critical blockchain technologies in China is shown in Figure 7. From 2016 to 2017, was the budding period of the technology, with a low number of patents and patent applicants. From 2017 to 2020, the

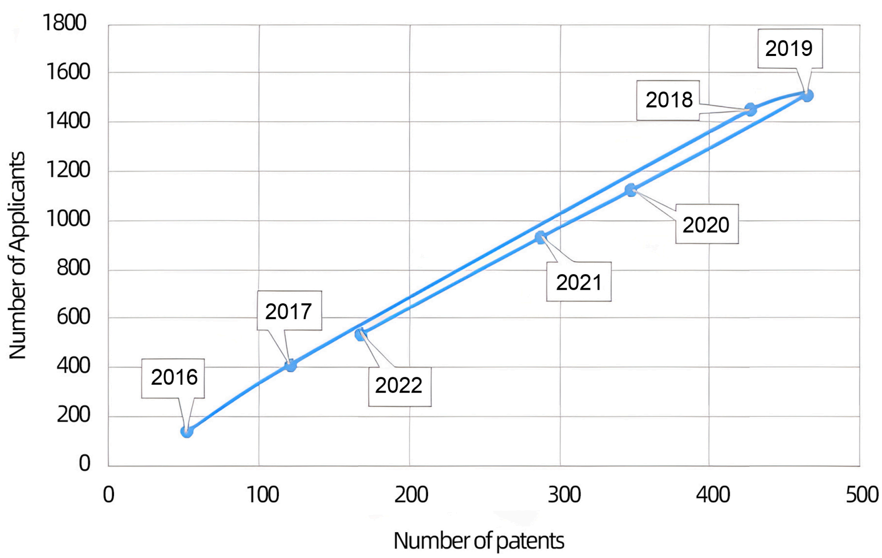

Figure 6. Lifecycle diagram of blockchain-critical technologies in the USA.

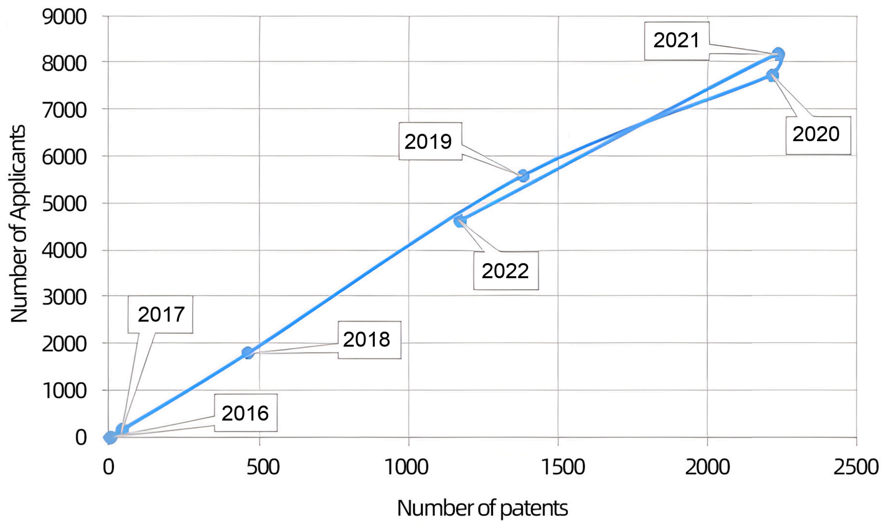

Figure 7. Lifecycle diagram of blockchain-critical technologies in China.

technology entered a rapid growth period, whereas from 2020 to 2021, the technology entered a mature period, with the number of patents remaining essentially unchanged and the number of patent applicants increasing slightly. After 2021, the number of patents and patent applicants has declined significantly, and the technology has entered a period of decline.

The critical technologies of the blockchain involved in this paper include consensus mechanisms, smart contracts, data storage, privacy protection, expansion technology, cross-chain technology, and peer-to-peer networks. The number of patent applications for each technology was counted separately, according to the time series. The critical technology features of blockchains in China and the USA are compared and analyzed with respect to the life cycle, as shown in **Figure 8** and **Figure 9**.

From the perspective of the underlying critical technologies of blockchain, the consensus mechanism, expansion technology, and peer-to-peer network rely on market applications to further promote technology iteration. China and the USA are relatively active in developing consensus mechanisms and peer-to-peer network technologies, with many invention patents and rich innovation results. The development of expansion technology could be faster, and the feasibility of practical applications still needs to be verified. The USA's rapid growth period in consensus mechanisms and peer-to-peer networks was from 2017 to 2019, followed by a maturity and decline period. China has a good development trend in this field, and companies, such as Alibaba and Tencent, have launched blockchain operation platforms and achieved breakthrough results. According to the curve points, the start of China's relevant technology maturity period is 2020, indicating that the consensus mechanism and peer-to-peer network have been fully validated and entered the market application promotion stage.

From the perspective of critical technologies in the middle layer of the blockchain, the USA started earlier than China in terms of privacy protection and

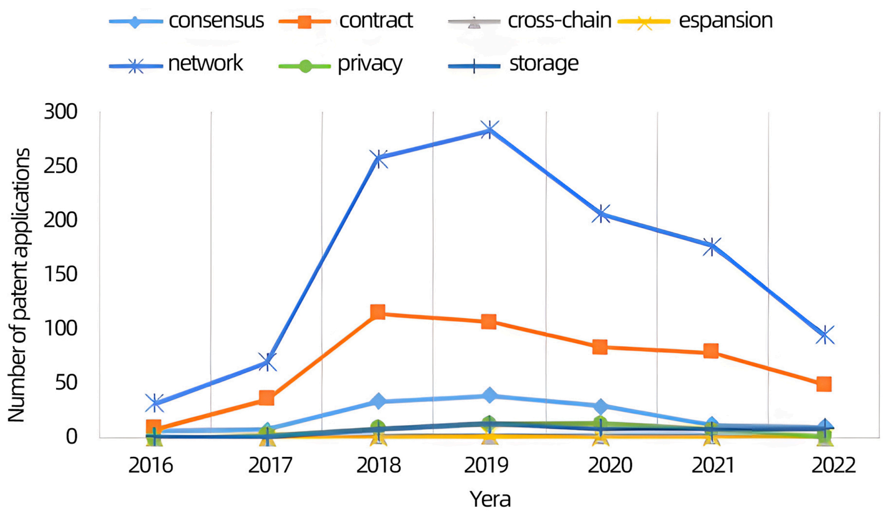

Figure 8. Life cycle trend chart of blockchain-critical technologies in the USA.

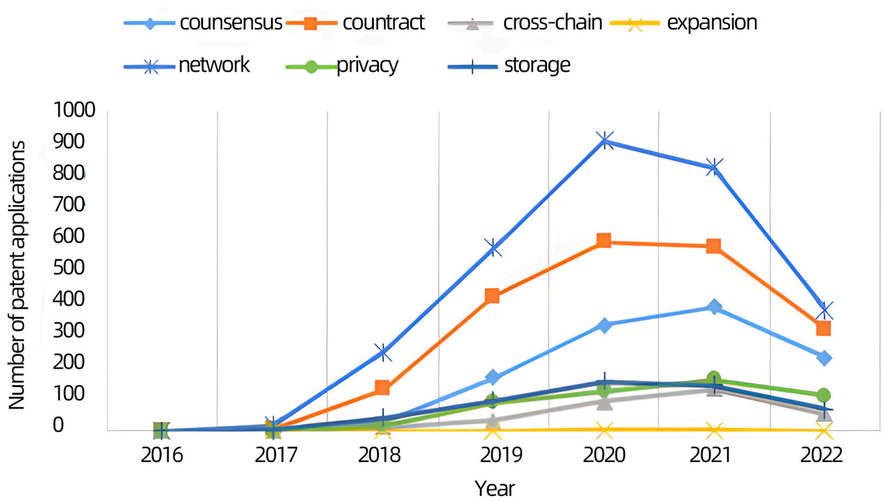

Figure 9. Life cycle trend chart of blockchain-critical technologies in China.

cross-chain technologies. For example, in 2014, Blockstream proposed sidechain technology to enhance transaction efficiency, improve interoperability, and form relatively mature products. In china, companies are also implementing technology such as Bubi beijing network technology co. ltd., but the related products need large-scale application tests. The number of invention patents in this field is relatively small in both China and the USA, and is growing slowly and is currently in the growth period.

From the perspective of blockchain application layer critical technology, with the widespread application of blockchain platforms, the programmability of smart contracts has expanded its application scope. From 2017 to 2019, the number of patents in China and the USA showed "explosive" growth, experienced a period of rapid development, and is now in a period of decline. The development of data storage can be faster, and there are differences in the storage requirements of different application scenarios. Therefore, it is necessary to consider security and efficiency. The number of patents in this field in China and the USA is relatively small and has a slow growth period.

5. Conclusions and Limitations

5.1. Research Conclusions

As an underlying technology framework with universal characteristics, blockchain brings profound changes to finance, technology, the economy, and other fields. Its development has received strong support from China and the USA. Patents related to blockchain-critical technologies can be indicators for measuring the progress of this technology. In this context, this study analyzes patents related to blockchain-critical technologies in China and the USA based on patentometrics. The main conclusions are as follows.

The overall trend of the number of patents for blockchain-critical technologies in China and the USA is rising first and then declining, with the United USA's blockchain-critical technology patents being laid out earlier than China's and more extensive than China's in terms of quantity. However, in 2019, China's patents in this field exploded, and the number of patents exceeded that of the USA. Overall, China has more patents on blockchain-critical technologies than the USA, which also reflects China's relatively active technology development activities and outstanding innovation capability in this field.

There are differences in the types of technologies active in blockchain-critical technologies between China and the USA. The USA is more active in blockchain consensus, smart contracts, and blockchain networks. Simultaneously, China is more active in blockchain consensus, smart contracts, privacy protection, data storage, blockchain networks, and cross-chain technologies. In terms of technical cooperation, both China and the USA have relatively loose cooperative networks with a low level of cooperation. Among them, one large-scale network exists in China, and the State grid corp china (SGCC-C) significantly influences the entire network.

According to the analysis of large IPC groups, the number of Chinese invention patents located in the core region exceeds that of the USA, but the top six IPC large groups are the same, namely, H04L-009, G06Q-020, G06F-016, H04L-029, G06F-021, and G06Q-040. The lifecycle of blockchain-critical technologies in China and the USA has entered a declining phase. From the perspective of each technology, consensus mechanisms, peer-to-peer networks, and smart contracts have entered the declining phase, whereas expansion technology, data storage, privacy protection, and cross-chain technology are still in the growth phase.

5.2. Limitations and Future Work

Although this study analyzes the current development status, competitive situation, and technical cooperation of blockchain-critical technologies in China and the USA using invention patent data, there are still some limitations. Blockchain is a globalized technology. In addition to the USA and China, countries such as Europe and South Korea have applied for many invention patents in this field. Patent data from more countries can be selected to further analyze critical blockchain technologies in the future. Second, many companies adopt the open-source approach of blockchain technology to provide a basis for the entire technology ecosystem. Some critical technologies need to be patented for inventions, which are not considered in this study.

In the future, we will continue to focus on developing critical blockchain technology. The research direction could be to measure the impact of regional policies on the development of blockchain-critical technologies and empirically study the industrial competition dynamics of blockchain technologies in China and the USA using indicators, such as invention patents.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abbas, A., Zhang, L., & Khan, S. U. (2014). A Literature Review on the State-of-the-Art in Patent Analysis. *World Patent Information, 37,* 3-13. https://doi.org/10.1016/j.wpi.2013.12.006

Abdelgawad, L., Kluegl, P., Genc, E., Falkner, S., & Hutter, F. (2020). Optimizing Neural Networks for Patent Classification. In U. Brefeld et al. (Eds.), *Machine Learning and Knowledge Discovery in Databases. ECML PKDD 2019. Lecture Notes in Computer Science* (pp. 688-703). Springer. https://doi.org/10.1007/978-3-030-46133-1_41

Abraham, B. P., & Moitra, S. D. (2001). Innovation Assessment through Patent Analysis. *Technovation, 21,* 245-252. https://doi.org/10.1016/S0166-4972(00)00040-7

Altuntas, S., Erdogan, Z., & Dereli, T. (2020). A Clustering-Based Approach for the Evaluation of Candidate Emerging Technologies. *Scientometrics, 124,* 1157-1177. https://doi.org/10.1007/s11192-020-03535-0

Archibugi, D., & Planta, M. (1996). Measuring Technological Change through Patents and Innovation Surveys. *Technovation, 16,* 451-519. https://doi.org/10.1016/0166-4972(96)00031-4

Arts, S., Hou, J., & Gomez, J. C. (2021). Natural Language Processing to Identify the Creation and Impact of New Technologies in Patent Text: Code, Data, and New Measures. *Research Policy, 50,* Article 104144. https://doi.org/10.1016/j.respol.2020.104144

Asuncion, F., Brinckman, A., Cole, D., Curtis, J., Davis, M., Dunlevy, T., Farmer, C., Harrison, A., Johnson, D. P., & Joyce, J. (2021). Connecting Supplier and DoD Blockchains for Transparent Part Tracking. *Blockchain: Research and Applications, 2,* Article 100017. https://doi.org/10.1016/j.bcra.2021.100017

Bains, P. (2022). *Blockchain Consensus Mechanisms: A Primer for Supervisors*. International Monetary Fund. https://doi.org/10.5089/9781616358280.063

Bamakan, S. M. H., Bondarti, A. B., Bondarti, P. B., & Qu, Q. (2021). Blockchain Technology Forecasting by Patent Analytics and Text Mining. *Blockchain: Research and Applications, 2,* Article 100019. https://doi.org/10.1016/j.bcra.2021.100019

Basberg, B. L. (1987). Patents and the Measurement of Technological Change: A Survey of the Literature. *Research Policy, 16,* 131-141. https://doi.org/10.1016/0048-7333(87)90027-8

Batubara, F. R., Ubacht, J., & Janssen, M. (2018). Challenges of Blockchain Technology Adoption for E-Government: A Systematic Literature Review. In *Proceedings of the 19th Annual International Conference on Digital Government Research: Governance in the Data Age* (pp. 1-19). Association for Computing Machinery. https://doi.org/10.1145/3209281.3209317

Benisi, N. Z., Aminian, M., & Javadi, B. (2020). Blockchain-Based Decentralized Storage Networks: A Survey. *Journal of Network and Computer Applications, 162,* Article 102656. https://doi.org/10.1016/j.jnca.2020.102656

Broadus, R. N. (1987). Toward a Definition of "Bibliometrics". *Scientometrics, 12,* 373-379. https://doi.org/10.1007/BF02016680

Cai, L., Sun, Y., Zheng, Z., Xiao, J., & Qiu, W. (2021). Blockchain in China. *Communications of the ACM, 64,* 88-93. https://doi.org/10.1145/3481627

Cangir, O. F., Cankur, O., & Ozsoy, A. (2021). A Taxonomy for Blockchain Based Distributed Storage Technologies. *Information Processing & Management, 58,* Article 102627. https://doi.org/10.1016/j.ipm.2021.102627

Chen, Y., & Bellavitis, C. (2020). Blockchain Disruption and Decentralized Finance: The Rise of Decentralized Business Models. *Journal of Business Venturing Insights, 13,* e00151. https://doi.org/10.1016/j.jbvi.2019.e00151

Chen, Y.-S., & Chang, K.-C. (2009). Using neural Network to Analyze the Influence of the Patent Performance upon the Market Value of the US Pharmaceutical Companies. *Scientometrics, 80,* 637-655. https://doi.org/10.1007/s11192-009-2095-2

Cong, L. W., & He, Z. (2019). Blockchain Disruption and Smart Contracts. *The Review of Financial Studies, 32,* 1754-1797. https://doi.org/10.1093/rfs/hhz007

Daim, T., Lai, K. K., Yalcin, H., Alsoubie, F., & Kumar, V. (2020). Forecasting Technological Positioning through Technology Knowledge Redundancy: Patent Citation Analysis of IoT, Cybersecurity, and Blockchain. *Technological Forecasting and Social Change, 161,* Article 120329. https://doi.org/10.1016/j.techfore.2020.120329

Dehghani, M., Mashatan, A., & Kennedy, R. W. (2021). Innovation within Networks-Patent Strategies for Blockchain Technology. *Journal of Business & Industrial Marketing, 36,* 2113-2125. https://doi.org/10.1108/JBIM-05-2019-0236

Delgado-Segura, S., Pérez-Solà, C., Herrera-Joancomartí, J., Navarro-Arribas, G., & Borrell, J. (2018). Cryptocurrency Networks: A New P2P Paradigm. *Mobile Information Systems, 2018,* Article ID: 2159082. https://doi.org/10.1155/2018/2159082

Denter, N. M. (2021). Blockchain Breeding Grounds: Asia's Advance over the USA and Europe. *World Patent Information, 67,* Article 102082. https://doi.org/10.1016/j.wpi.2021.102082

Dolfsma, W., & Leydesdorff, L. (2011). Innovation Systems as Patent Networks: The Netherlands, India and Nanotech. *Innovation, 13,* 311-326. https://doi.org/10.5172/impp.2011.13.3.311

Ernst, H. (2003). Patent Information for Strategic Technology Management. *World Patent Information, 25,* 233-242. https://doi.org/10.1016/S0172-2190(03)00077-2

Filippova, E. (2019). Empirical Evidence and Economic Implications of Blockchain as a General Purpose Technology. In *2019 IEEE Technology & Engineering Management Conference (TEMSCON)* (pp. 1-8). IEEE. https://doi.org/10.1109/TEMSCON.2019.8813748

Griliches, Z. (1998). Patent Statistics as Economic Indicators: A Survey. In *R&D and*

Productivity: The Econometric Evidence (pp. 287-343). University of Chicago Press.

Harhoff, D., Narin, F., Scherer, F. M., & Vopel, K. (1999). Citation Frequency and the Value of Patented Inventions. *Review of Economics and Statistics, 81,* 511-515. https://doi.org/10.1162/003465399558265

Hu, Y., Hou, Y. G., Oxley, L., & Corbet, S. (2021). Does Blockchain Patent-Development Influence Bitcoin Risk? *Journal of International Financial Markets, Institutions and Money, 70,* Article 101263. https://doi.org/10.1016/j.intfin.2020.101263

Huang, L.-Y., Cai, J.-F., Lee, T.-C., & Weng, M.-H. (2020). A Study on the Development Trends of the Energy System with Blockchain Technology Using Patent Analysis. *Sustainability, 12,* Article 2005. https://doi.org/10.3390/su12052005

Ismanto, L., Ar, H. S., Fajar, A., & Bachtiar, S. (2019). Blockchain as E-Commerce Platform in Indonesia. *Journal of Physics: Conference Series, 1179,* Article 012114. https://doi.org/10.1088/1742-6596/1179/1/012114

Jang, W., Park, Y., & Seol, H. (2021). Identifying Emerging Technologies Using Expert Opinions on the Future: A Topic Modeling and Fuzzy Clustering Approach. *Scientometrics, 126,* 6505-6532. https://doi.org/10.1007/s11192-021-04024-8

Jiang, N., Liu, X., & Xu, M. (2021). Evaluating Blockchain Technology and Related Policies in China and the USA*. Science and Public Policy, 48,* 562-575. https://doi.org/10.1093/scipol/scab032

Kakavand, H., Kost De Sevres, N., & Chilton, B. (2017). The Blockchain Revolution: An Analysis of Regulation and Technology Related to Distributed Ledger Technologies. https://doi.org/10.2139/ssrn.2849251

Khan, S. N., Loukil, F., Ghedira-Guegan, C., Benkhelifa, E., & Bani-Hani, A. (2021). Blockchain Smart Contracts: Applications, Challenges, and Future Trends. *Peer-to-Peer Networking and Applications, 14,* 2901-2925. https://doi.org/10.1007/s12083-021-01127-0

Lashkari, B., & Musilek, P. (2021). A Comprehensive Review of Blockchain Consensus Mechanisms. *IEEE Access, 9,* 43620-43652. https://doi.org/10.1109/ACCESS.2021.3065880

Li, H., & Li, M. (2022). Patent Data Access Control and Protection Using Blockchain Technology. *Scientific Reports, 12,* Article No. 2772. https://doi.org/10.1038/s41598-022-05215-w

Lin, S., Kong, Y., Nie, S., Xie, W., & Du, J. (2021). Research on Cross-Chain Technology of Blockchain. In *2021 6th International Conference on Smart Grid and Electrical Automation (ICSGEA)* (pp. 405-408). IEEE. https://doi.org/10.1109/ICSGEA53208.2021.00098

Lin, Y. (2008). Review of Knowledge Measurement Research Based on Patent Data. *Science and Technology Management Research, 9,* 91-93.

Liu, Q., Song, B., & Wang, J. (2022). Second-Degree Branch Structure Blockchain Expansion Model. *International Journal of Distributed Sensor Networks, 18*. https://doi.org/10.1177/15501477211064755

Liu, Z., & Li, Z. (2020). A Blockchain-Based Framework of Cross-Border E-Commerce Supply Chain. *International Journal of Information Management, 52,* Article 102059. https://doi.org/10.1016/j.ijinfomgt.2019.102059

Massaro, M. (2021). Digital Transformation in the Healthcare Sector through Blockchain Technology. Insights from Academic Research and Business Developments. *Technovation, 120,* Article 102386. https://doi.org/10.1016/j.technovation.2021.102386

Mattke, J., Hund, A., Maier, C., & Weitzel, T. (2019). How an Enterprise Blockchain Application in the US Pharmaceuticals Supply Chain is Saving Lives. *MIS Quarterly Executive, 18,* Article 6. https://doi.org/10.17705/2msqe.00019

Nan, J., Xing, L., & Ming, X. (2022). Measuring Technological Collaboration on Blockchain Based on Patents: A Social Network Analysis Approach. *Science, Technology and Society, 27,* 66-87. https://doi.org/10.1177/09717218211032902

Narin, F. (1994). Patent Bibliometrics. *Scientometrics, 30,* 147-155. https://doi.org/10.1007/BF02017219

Narin, F. (1995). Patents as Indicators for the Evaluation of Industrial Research Output. *Scientometrics, 34,* 489-496. https://doi.org/10.1007/BF02018015

Natarajan, H., Krause, S., & Gradstein, H. (2017). *Distributed Ledger Technology and Blockchain*. The World Bank Group. https://doi.org/10.1596/29053

Norman, P. M. (2002). Protecting Knowledge in Strategic Alliances: Resource and Relational Characteristics. *The Journal of High Technology Management Research, 13,* 177-202. https://doi.org/10.1016/S1047-8310(02)00050-0

Ozcan, S., & Unalan, S. (2020). Blockchain as a General-Purpose Technology: Patentometric Evidence of Science, Technologies, and Actors. *IEEE Transactions on Engineering Management, 69,* 792-809. https://doi.org/10.1109/TEM.2020.3008859

Pillai, B., Biswas, K., & Muthukkumarasamy, V. (2020). Cross-Chain Interoperability among Blockchain-Based Systems Using Transactions. *The Knowledge Engineering Review, 35,* e23. https://doi.org/10.1017/S0269888920000314

Prahalad, C. K., & Mashelkar, R. A. (2010). Innovation's Holy Grail. *Harvard Business Review, 88,* 132-141.

Price, D. J. (1986). *Little Science, Big Science... and Beyond* (Vol. 480). Columbia University Press.

Reisman, R. J. (2019). Air Traffic Management Blockchain Infrastructure for Security, Authentication, and Privacy. *AIAA Scitech Forum*. https://ntrs.nasa.gov/api/citations/20190000022/downloads/20190000022.pdf

Saghiri, A. M. (2020). Blockchain Architecture. In S. Kim, & G. Deka (Eds.), *Advanced Applications of Blockchain Technology* (pp. 161-176). Springer. https://doi.org/10.1007/978-981-13-8775-3_8

Sharples, M., & Domingue, J. (2016). The Blockchain and Kudos: A Distributed System for Educational Record, Reputation and Reward. In K. Verbert, M. Sharples, & T. Klobučar (Eds.), *Adaptive and Adaptable Learning. EC-TEL 2016. Lecture Notes in Computer Science* (pp 490-496). Springer. https://doi.org/10.1007/978-3-319-45153-4_48

Sigley, G., & Powell, W. (2023). Governing the Digital Economy: An Exploration of Blockchains with Chinese Characteristics. *Journal of Contemporary Asia, 53,* 648-667. https://doi.org/10.1080/00472336.2022.2093774

Someda, H., Akagi, T., & Kajikawa, Y. (2022). An Analysis of the Spillover Effects Based on Patents and Inter-Industrial Transactions for an Emerging Blockchain Technology. *Scientometrics, 127,* 4299-4314. https://doi.org/10.1007/s11192-022-04457-9

Syed, T. A., Alzahrani, A., Jan, S., Siddiqui, M. S., Nadeem, A., & Alghamdi, T. (2019). A Comparative Analysis of Blockchain Architecture and Its Applications: Problems and Recommendations. *IEEE Access, 7,* 176838-176869. https://doi.org/10.1109/ACCESS.2019.2957660

Trajtenberg, M., Henderson, R., & Jaffe, A. (1997). University versus Corporate Patents: A Window on the Basicness of Invention. *Economics of Innovation and New Technology, 5,* 19-50. https://doi.org/10.1080/10438599700000006

Trappey, A., Trappey, C. V., & Hsieh, A. (2021). An Intelligent Patent Recommender Adopting Machine Learning Approach for Natural Language Processing: A Case Study for Smart Machinery Technology Mining. *Technological Forecasting and Social Change, 164,* Article 120511. https://doi.org/10.1016/j.techfore.2020.120511

Verbeek, A., Debackere, K., Luwel, M., Andries, P., Zimmermann, E., & Deleus, F. (2002). Linking Science to Technology: Using Bibliographic References in Patents to Build Linkage Schemes. *Scientometrics, 54,* 399-420. https://doi.org/10.1023/A:1016034516731

Wang, J., Chen, W., Wang, L., Ren, Y., & Sherratt, R. S. (2020). Blockchain-Based Data Storage Mechanism for Industrial Internet of Things. *Intelligent Automation & Soft Computing, 26,* 1157-1172. https://doi.org/10.32604/iasc.2020.012174

Wang, T., Zhao, C., Yang, Q., Zhang, S., & Liew, S. C. (2021). Ethna: Analyzing the Underlying Peer-to-Peer Network of Ethereum Blockchain. *IEEE Transactions on Network Science and Engineering, 8,* 2131-2146. https://doi.org/10.1109/TNSE.2021.3078181

Wu, H., Shen, G., Lin, X., Li, M., Zhang, B., & Li, C. Z. (2020). Screening Patents of ICT in Construction Using Deep Learning and NLP Techniques. *Engineering, Construction and Architectural Management, 27,* 1891-1912. https://doi.org/10.1108/ECAM-09-2019-0480

Xu, X., Weber, I., Staples, M., Zhu, L., Bosch, J., Bass, L., Pautasso, C., & Rimba, P. (2017). A Taxonomy of Blockchain-Based Systems for Architecture Design. In *2017 IEEE International Conference on Software Architecture (ICSA)* (pp. 243-252). IEEE. https://doi.org/10.1109/ICSA.2017.33

Yaga, D., Mell, P., Roby, N., & Scarfone, K. (2019). Blockchain Technology Overview. arXiv preprint arXiv:1906.11078. https://doi.org/10.6028/NIST.IR.8202

Yang, Y.-J., & Hwang, J.-C. (2020). Recent Development Trend of Blockchain Technologies: A Patent Analysis. *International Journal of Electronic Commerce Studies, 11,* 1-12. https://doi.org/10.7903/ijecs.1931

Yoon, J., & Kim, K. (2012). An Analysis of Property-Function Based Patent Networks for Strategic R&D Planning in Fast-Moving Industries: The Case of Silicon-Based Thin Film Solar Cells. *Expert Systems with Applications, 39,* 7709-7717. https://doi.org/10.1016/j.eswa.2012.01.035

Yu, D., & Pan, T. (2021). Identifying Technological Development Trajectories in Blockchain Domain: A Patent Citation Network Analysis. *Technology Analysis & Strategic Management, 33,* 1484-1497. https://doi.org/10.1080/09537325.2021.1879381

Yuan, Y., & Wang, F.-Y. (2018). Blockchain and Cryptocurrencies: Model, Techniques, and Applications. *IEEE Transactions on Systems, Man, and Cybernetics: Systems, 48,* 1421-1428. https://doi.org/10.1109/TSMC.2018.2854904

Zanella, G., Liu, C. Z., & Choo, K.-K. R. (2023). Understanding the Trends in Blockchain Domain through an Unsupervised Systematic Patent Analysis. *IEEE Transactions on Engineering Management, 70,* 1991-2005.

Zhang, H., Daim, T., & Zhang, Y. P. (2021). Integrating Patent Analysis into Technology Roadmapping: A Latent Dirichlet Allocation Based Technology Assessment and Roadmapping in the Field of Blockchain. *Technological Forecasting and Social Change, 167,* Article 120729. https://doi.org/10.1016/j.techfore.2021.120729

Zheng, J., Zhao, Z.-Y., Zhang, X., Chen, D.-Z., & Huang, M.-H. (2014). International Collaboration Development in Nanotechnology: A Perspective of Patent Network Analysis. *Scientometrics, 98,* 683-702. https://doi.org/10.1007/s11192-013-1081-x

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. In *2017 IEEE International Congress on Big Data (BigData Congress)* (pp. 557-564). IEEE. https://doi.org/10.1109/BigDataCongress.2017.85