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Blockchain Technology Application Maturity Assessment Model for Digital Government Public Service Projects

Yutao Yang[1], Yuxuan Shi[1], and Tianmei Wang[1] ✉

ABSTRACT

With the deepening application of blockchain technology, exaggerating its empowering effects has become common. In recent years, the rational assessment of the maturity of blockchain technology applications in digital projects in different fields has been the focus of attention and identified as the key to improving the implementation effect of various digital projects. Although some studies have obtained substantial research results on technology maturity and its derivative applications, which can be used to predict the overall trend of a technology or guide the implementation of the technology on the ground, few studies have evaluated the maturity of blockchain technology in combination with different application scenarios. Our study combines application scenarios and the technical characteristics of blockchain technology and proposes an evaluation system for blockchain technology application maturity consisting of five primary indicators, that is, key application requirements, data security, process complexity, application ecological completeness, and technical performance requirements, and their corresponding secondary indicators. In addition, we take digital government public service projects as application scenarios and use the analytic hierarchy process (AHP) entropy method and expert scoring method to determine the weights corresponding to each index in the assessment system and construct a blockchain technology application maturity assessment model. Moreover, we apply the model to ten typical digital government public service projects to conduct a comprehensive assessment and analysis. By comparing the indicator scores of the different projects, we analyze the project characteristics influencing blockchain technology application maturity and provide suggestions for applying “blockchain + digital government public services”.

KEYWORDS

blockchain; digital government public services; technical maturity; analytic hierarchy process (AHP); AHP-entropy weight method

Since its creation by Satoshi Nakamoto in 2008, bitcoin has gradually entered the public perspective, and the technology community has been paying increasing attention to digital currency. Blockchain, as the core technology of bitcoin, has developed rapidly in recent years because of its traceability, high transparency, immutability, distribution, and decentralization characteristics and is widely used in various industries apart from digital currency[1]. On the basis of Gartner’s technology maturity curve, blockchain was listed among the top five technology trends in 2018[2]. On 24 October 2019, during the 18th collective study of the Central Political Bureau, Xi Jinping, general secretary of the CPC Central Committee, emphasized that accelerating blockchain technology development to promote high-quality economic and social development is essential for facilitating the establishment of secure and credible rules and order of the digital economy and enhancing the modernization of the national governance system and governance capacity.

According to the “Blockchain White Paper” (2020) issued by the China Academy of Information and Communication Research, the governments of various countries initiated or participated in 236 blockchain technology experimental projects from 2012 to 2020[3]. In the distribution of blockchain technology project types, projects on government affairs accounted for 32% of the total, and the remaining types included projects in the financial industry, digital currency, medical and healthcare, digital identity, justice, and intellectual property. After more than ten years of precipitousness, blockchain technology basically passed the technology budding period, expectation expansion period, and bubble bursting period predicted by Gartner’s technology maturity curve and is gradually entering the steady climbing recovery period. That is, capital enthusiasm is gradually cooling, and industry investment is becoming rational, as manifested by the substantial decline in the number of new blockchain enterprises worldwide in 2019. However, the fever for blockchain technology application in various fields in China, such as finance, energy, logistics, and particularly digital government public services, has yet to subside, and the phenomenon of deifying blockchain empowerment is common. Therefore, effectively assessing how blockchain technology can empower various digital projects to reward limited investment is important. Blockchain technology application maturity assessment is important for identifying new technology application opportunities and prospects and guiding the investment planning of relevant departments.

Many studies have focused on assessing technology application maturity, such as those that used Gartner’s technology maturity curve for predictions, those that used the NASA technology readiness level (TRL), manufacturing readiness level (MRL), and technology maturity difficulty level for assessments[4], or those that used a generic definition of technology maturity for assessments by further generalizing the TRL[5]. However, the above approaches have certain limitations. Specifically, Gartner’s maturity curve is

1 School of Information, Central University of Finance and Economics, Beijing 100098, China
Address correspondence to Tianmei Wang, wangtianmei@cufe.edu.cn

related to application value returns and media hype fever after the birth of a technology but does not correlate well with the maturity of the technology for actual application, and researchers have paid little attention to the actual Gartner maturity curve of emerging technologies[6]. The TRL, MRL, and other assessment approaches are generally applied to technologies from birth to assessment, in which the highest level of maturity can generally achieve the application objective, that is, land a project. However, these approaches are not applicable to the application maturity assessment of technologies such as blockchain, which has developed and been applied for a long period and has successfully landed projects in several fields.

Simultaneously, because there are substantial differences between digital projects in different application industries, evaluating the maturity of new technologies, particularly blockchain technology, in conjunction with application scenarios is necessary. Otherwise, deepening, refining, and effectively guiding practice would be difficult. Presently, blockchain technology is widely used in finance, energy, insurance, logistics, manufacturing, and so on, and has gained practical experience in the field of government public management in the United States, Japan, and Estonia. Compared with industry and commerce, the digitization process in the Chinese government is relatively brief. However, as a key area of national digital development, government public services related to livelihood are of considerable concern in the process of digital government construction and governance implementation. Exploring how to use blockchain technology to optimize the supply mode of digital government public services and enhance the implementation effect of digital government public service projects has become urgent. Therefore, this study takes digital government public service projects as application scenarios and builds a blockchain technology application maturity assessment model to provide a theoretical basis for improving the implementation effect of blockchain technology in digital government public service projects.

On the basis of blockchain-related research and practical applications, this study combines the concept and framework of technological maturity and proposes the concept of blockchain technology application maturity, which is defined as the maturity of blockchain technology applied to actual projects. On the basis of existing blockchain research and the literature, this study proposes an application maturity assessment index system for blockchain technology in combination with digital government public service project application scenarios[7]. In addition, this study adopts the analytic hierarchy process (AHP) entropy weight and expert scoring methods to determine the weights of the assessment indices and then constructs a blockchain technology application maturity assessment model for the digital government public service projects. On this basis, this study assesses the blockchain technology application maturity in the landed digital government public service projects to dissect the feasibility of blockchain technology applications and provide a reference for assessing other projects applying blockchain technology. This study aims to provide a theoretical basis for assessing blockchain technology application maturity and a decision basis for the subsequent and future application of blockchain technology by relevant departments.

1 Literature Review

1.1 Research on blockchain technology applications

A blockchain is a distributed, shared digital ledger supported by cryptography and stored in chronological order. A blockchain can be divided into three categories[8]: a public chain represented by bitcoin, a semipublic state of a consortium chain used within organizations, and a completely closed, private chain. Blockchain technology is a distributed network data management technology that uses cryptography and distributed consensus protocols to ensure network transmission and access security and achieve multiparty data maintenance, cross-validation, networkwide consistency, and minimal tampering. As an important evolution of the new generation of information and communication technologies, blockchain technology can provide new ideas for the management and value release of data elements and a novel way to establish a credible collaboration network across industrial entities. China’s blockchain technology industry is booming, with the industry scale and number of enterprises increasing, international competitiveness substantially improving, and vertical industry application in landed projects emerging. Blockchain technology should play an increasingly important role in global economic recovery and digital economy development after the pandemic.

With the rapid development and widespread practical implementation of blockchain technology, an increasing number of scholars have focused on examining and analyzing application scenarios, development prospects, and the ensuing social impact of the technology in various fields, particularly in government departments. As industry policymakers and reform advocates promote the technology to the public and application organizations after fully demonstrating its usability and security, which can help in the reform, the participants are accepting the reform measures, clarifying the scope of the use of personal data, and accelerating the implementation of reform policies. Because of its multiple characteristics, blockchain technology can be used in rich industry fields and public affairs service scenarios, such as information, finance, compliance, culture, and healthcare. Wu and Yan[9] explored the degree of matching between blockchain technology and “Internet + taxation” from the perspective of the development characteristics of blockchain technology and used actual cases to support the study. Ye and Wang[10] argued that applying blockchain technology to e-government services, such as citizen identity authentication, citizen and organization integrity management, government information disclosure, video traceability supervision, and cadre personnel file management, would help improve the relationship between the government, enterprises, and the public, thereby enhancing government credibility and promoting the provision of improved services for enterprises and the public. Wang and Lu[11] identified the application direction of blockchain technology in government public affairs and governance based on a feasibility analysis of specific government business application scenarios of relevant government departments. Moreover, the authors believed that blockchain technology would bring opportunities to government businesses, such as data management mode upgrades and the rapid definition of governance rules, but simultaneously face existing institutional arrangements, technicalized supervision, and other challenges. American economist Melanie Swan[12] proposed various scenarios in which blockchain technology can be used and believed that using blockchain technology for permanent public records could help in the efficient and decentralized storage of documents such as passports, land transaction information, and various contracts to assist the government in providing personalized services.

1.2 Research on technology maturity assessment models

The TRL concept originated from NASA and is a technology evaluation index dividing technology maturity into nine levels to evaluate technology development, improve the science of decision-making, as well as reduce the risk of applying new technologies[13]. This assessment method reflects the degree to which a technology meets the desired goals of a project[14]. The method originated from NASA and was promoted for use by the US Department of Defense (DOD). Generic definitions of technology maturity based on this method were proposed for assessment efforts in other technology areas[15]. However, the TRL and generic technology maturity definitions are generally used at the birth of a technology to judge when it has reached maturity to be applied based on whether technology application on the ground exists. Therefore, this assessment method is not applicable to the application maturity assessment of technologies such as blockchain in landed projects.

The MRL, which is a manufacturing risk management tool used by the US DOD in acquisition management[16], was developed based on the TRL, specializing in manufacturing. However, because of the overly specific nature of the MRL, its level descriptions are generally applicable only to the maturity assessment of actual manufacturing processes, and the standard is not applicable to judging the application maturity of system-based technology such as blockchain.

The software capability maturity model (CMM) is a highly mature assessment model. In essence, it is a systematic approach to enhancing software by improving the software process[17]. The CMM is generally applied to the software development process, and its main role is to continuously improve a particular software program, targeting the extent to which it meets certain requirements and solves problems. Therefore, the CMM is not suitable for judging the maturity of a technology in a particular application scenario.

Gartner proposed the technology maturity curve (hype cycle) to predict the development cycle of a technology. The technology maturity curve divides the technology development cycle into five stages and consists of a combination of the value return curve of a technology and the expectation change curve influenced by hype, with the maturity value curve having a higher value than the two other curves[18]. However, the technology maturity curve is generally used as a reference in the field of industry investment and for the overall development trend and cannot be used to assess the application maturity of a particular project technology.

1.3 Research on digital government public service project characteristics

Wang[19] defined digital government as the elaboration of the information technology revolution, a new form of government in the information age, and a government reinventing itself on the basis of the original traditional electronic government. The connotation of digital government lies in achieving goals such as paperless public services, accurate social governance, and scientific government decision-making with the help of cloud computing, big data, and other information and communication technologies to facilitate the overall digitalization of the economy and society. Since the end of the 20th century, constructing the digital government has been an important area in the implementation of China's information technology strategy.

The reports[20] of the 19th Party Congress and the 4th Plenary Session of the 19th Central Committee clearly proposed for the government to strengthen the use of the Internet, big data, artificial intelligence, and other technical means to promote the construction of the digital government. Thus, governments worldwide are gradually building digital governments and new service-oriented governments and issuing relevant policy documents for guidance. For example, Beijing proposed to integrate the digital government, digital economy, and digital society, build a basic standardized urban information coding system, promote the initial scale of a universal and orderly urban sensing system, and realize the "one network management" of urban operations and management. In addition, the city planned to implement the "ten hundred thousand" project, focus on developing intelligent transportation, intelligent municipalities, intelligent education, intelligent medical care, and intelligent elderly care, improve the level of intelligent services in livelihoods, solve the problem of the "digital divide" in the use of intelligent technology by the elderly, and create a universal and convenient intelligent lifestyle.

Digital government public services can provide online public services through digital information. On one hand, digital government public services should meet the needs of existing public services. On the other hand, such services should improve the ways and means of providing traditional public services. For example, the Danish government's Digital Strategic Plan 2016–2020 launched in 2016 aimed to build a strong and secure digital Denmark by integrating and coordinating public services, particularly between the local, regional, and central governments, to create a comprehensive digital public sector. Specifically, citizens can easily access government services, such as filing taxes, booking appointments with doctors and hairdressers, and enrolling their children in kindergarten, using their digital ID card, which is typical of how digital governments provide public services. Unlike traditional public services, digital government public services can provide the public with more convenient channels and shorten the waiting time to obtain services and receive audits while reducing the costs associated with paper-based data archiving, thereby decreasing government work costs, increasing efficiency, and so on.

With the expansion of digital government public services, on April 26 2016, the General Office of the State Council of China officially released the "State Office Issued [2016] No. 23" document, and the National Development and Reform Commission, Ministry of Finance, Ministry of Education, Ministry of Public Security, and ten other departments jointly issued "Promote Internet +" government services to conduct the pilot implementation information plan for citizens. The program clearly proposed addressing government service matters, with "one application, a window to accept, a network to do" as the main task, to realize three changes, that is, from "masses run errands" to "information run", from "masses to run back and forth" to "departmental coordination to do", and from "passive services" to "active services", in 80 pilot cities for a gradual national promotion. According to the "2019 China Digital Government Service Capability Assessment General Report" released by the China Software Evaluation Center, as of November 2019, 10 provincial governments in China introduced and publicized their digital government plans. The province-wide integrated comprehensive online service hall established in Guizhou Province and the integrated online government created in Zhejiang Province exemplify intelligent digital governments implemented by local governments based on their actual situation.

On the basis of the perspective of information system users, digital government public service projects can be divided into three types, namely, public-oriented, enterprise-oriented, and government-oriented projects. Public-oriented digital government public service projects actively respond to the public's complex and diverse public service needs by extensively using digital technology to enable the public to enjoy the convenience and efficiency provided by digital public services, such as epidemic prevention and control and online service halls. Digital government public service projects for enterprises use digital technology to realize enterprise data sharing, data management, and other functions to facilitate business processes and increase data transmission security, such as financial service platforms for small and medium-sized enterprises (SMEs) and online office halls for enterprises. Government-oriented digital government public service projects use digital technology to simplify approval materials, optimize the approval process, reduce application costs, solve the problem of inconvenient government data circulation and interaction, and improve collaboration efficiency among various government departments, such as the Beijing joint approval platform and government affairs collaboration platform.

1.4 Literature review conclusion

As a rising star among the new generation of information technologies, blockchain technology is widely used in the field of finance, insurance, energy, logistics, public administration, and so on. Scholars at home and abroad have conducted in-depth research on blockchain technology and its application and have obtained abundant research results[21].

Therefore, rationally assessing the maturity of blockchain technology application in practical fields is essential. However, how can the application maturity of blockchain technology be assessed effectively? This question underscores not only a key practical issue but also an important research issue that must be explored in blockchain technology applications. However, the research results show that few studies have explored three main aspects of this issue in depth.

First, many studies on blockchain technology applications have focused on the concept and its specific features, underlying architecture, application features, and possible impact on the government, society, and the public. However, few studies have examined the maturity of blockchain technology applications combined with specific scenarios.

Second, although abundant technology maturity assessment research results have been obtained and numerous technology maturity assessment models exist, some of which can make maturity and investment predictions on general technology trends and conduct maturity grading assessments for unimplemented technology, none can be used for blockchain technology maturity assessment.

Finally, assessing technology application maturity depends on a combination of specific scenarios. As a key area of the national digital strategy, blockchain technology research and application in digital government public services are changing day by day, but studies have yet to focus on specific application scenarios and explore maturity assessment methods for blockchain technology application.

2 Constructing a Blockchain Technology Application Maturity Assessment Model

2.1 Design of the assessment model index system

To ensure that the blockchain technology application maturity assessment model is scientifically and reasonably designed and can provide practical guidance, this study takes the three types of digital government public service projects as examples for constructing the model. As mentioned in the "Blockchain White Paper"[19] of the China Academy of Information and Communication Research, blockchain technology applications must meet certain conditions, and the application area must reflect the irreplaceability of blockchain technology.

The characteristics of blockchain technology make it highly suitable for risk-free, high-value, and easy-to-implement application scenarios, wherein high application value can be obtained. "Risk-free" indicates the absence of security risks or other hidden dangers that may lead to abnormal project operations. Meanwhile, "high-value" means that certain demands in the current application scenario must be addressed, and using blockchain technology can meet such demands and realize cost reduction and efficiency improvement expectations. Finally, "easy-to-implement" means that in an application scenario, the conditions related to the application of blockchain technology are complete, and the implementation difficulty level is low. As a "risk-free" application scenario is difficult to achieve, this study expands the scope to consider "low-risk" application scenarios.

As an important area of the national digitalization strategy, the application scenario of digital government public service projects demonstrates "high-value" characteristics. However, digital government construction has accumulated certain digitalization experiences after more than 20 years, thus, this application scenario also has certain "low-risk" and "easy-to-implement" characteristics. Therefore, blockchain technology has considerable application potential in digital government public service projects. On the basis of the "high-value", "low-risk", and "easy-to-implement" characteristics of digital government public service projects combined with two rounds of in-depth interviews with blockchain experts, this study selects a representative characteristic. In addition, five first-level indicators are selected, including "key application requirements" based on "high value", "data security" based on "low-risk" and "high-value", "process complexity", "application ecological completeness", and "technical performance requirements" based on "ease of implementation". Furthermore, combining the systematic, scientific nature and characteristics of the indicators, 18 secondary indicators are selected to build the blockchain technology application maturity assessment model (Fig. 1). The detailed explanations for selecting the indicators are presented below.

2.1.1 Key application requirements

In the "Reinventing Production Relationships with the Power of Decentralization —Blockchain Industry Report"[22], the 36 Krypton Institute proposed that the "blockchain +" project application scenario should meet at least three characteristics: (1) demand for a ledger in the application scenario, (2) demand for ledger record authenticity, and (3) demand for a large-scale consensus among the multiple nodes and organizations. The value of blockchain technology to a particular application scenario depends on the degree of demand for the three types of requirements in the application scenario.

The application demand measure consists of three secondary indicators: demand for ledger data complexity, demand for data authenticity, and demand for a large-scale consensus. The three indicators are positive, that is, the higher the demand, the higher the value and the higher the blockchain technology application maturity. The indicators are described in Table 1.

2.1.2 Data security

The data security indicators measure the security risk of the blockchain technology project application. Government data are mostly large and complex big data, and the credibility of the data source should be fully considered before placing the data on the

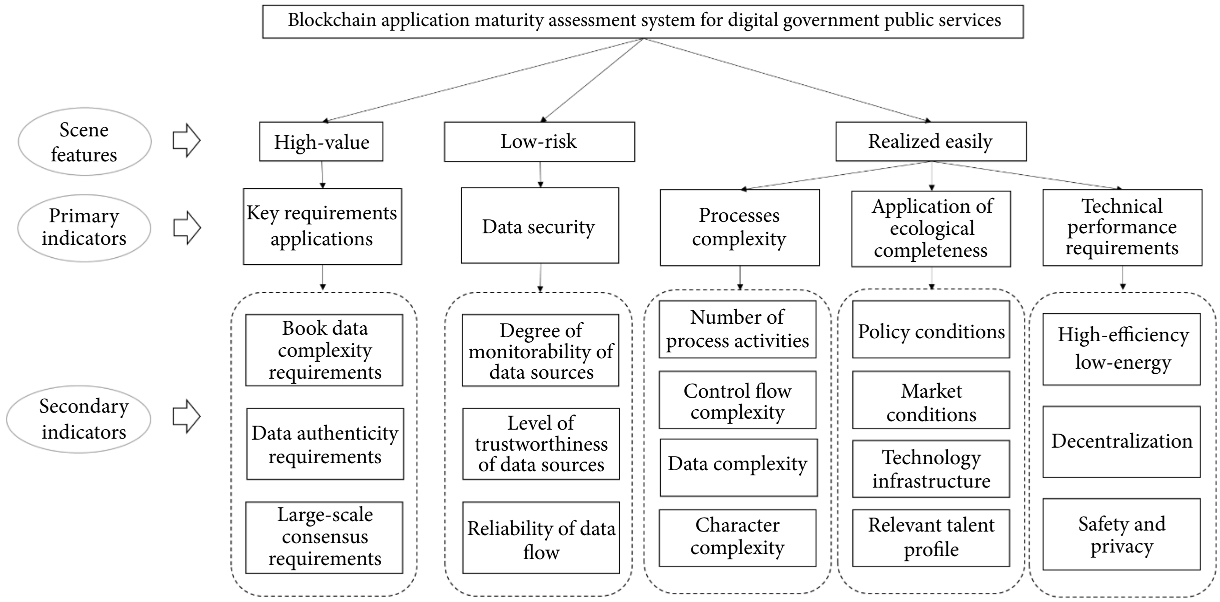

Fig. 1 Framework of index system.

Table 1 Description of blockchain technology application maturity evaluation index system.

Application scenario characteristic	Primary indicator	Secondary indicator	Indicator description
High-value	Key application requirements	Ledger data complexity	Type of ledger required for a scenario (simple numerical data, complex semi-structured, or unstructured data, such as text, audio, and pictures)
		Data authenticity	Degree of data authenticity required for a scenario (application scenario users' urgency to record the data flow process and ensure the authenticity of all aspects of the flow)
		Large-scale consensus	Extent to which a scenario requires a large-scale consensus (application scenario users' degree of urgency for data consistency)
Low-risk	Data security	Data source monitorability degree	Degree to which data source quality can be effectively monitored in a scenario; the higher the degree is, the more effective the reduction of possible risks and additional costs associated with low-quality data sources
		Data source trustworthiness degree	Degree to which a data source can be trusted in a scenario (because of personnel quality, data complexity, and other issues, data source quality may vary; the higher the degree of trust is, the more effective the reduction of risks and additional costs associated with low-quality data from data sources)
		Data flow reliability degree	Degree of reliability of the data flow process in a scenario (including relevant policies and technical means to support the degree of reliability of data flow processes)
Realized easily	Process complexity	Number of process activities	Number of processes involoves in this scenario

chain. If the data source is forged, then it will lead to the wrong conclusions. If the data application scenario is clear, then the belief that the data are deliberately created, and a type of "illusion" will exist to induce analysts to draw conclusions in their favor. As false information is generally hidden in large amounts of information, people cannot identify the authentic information and thus make misjudgments. The impact of this situation should not be underestimated. Furthermore, identifying the authenticity of all the data sources using information security technology is difficult.

If the data source is not trusted, then whether the data source can be supervised effectively to prevent the risks brought about by the harmful information on the chain will be considered. After the data are placed on the chain, the data flow security and transaction process should be tested to prevent the gradual distortion of the data in the dissemination due to the untamperable characteristics of the data on the blockchain.

The data security measure is composed of three indicators: the degree of data source monitorability, the degree of data source trustworthiness, and the degree of data process transfer reliability. The three indicators are positive, that is, the higher the degree, the higher the data security and the higher the blockchain technology application maturity. The details of the indicators are presented in Table 1.

2.1.3 Process complexity

As the complexity of the project process is positively correlated with the difficulty of the blockchain technology application implementation, process complexity is introduced as a measure of whether blockchain technology can be implemented. The process complexity measure consists of four indicators: the number of process activities[23], control process complexity[24], data complexity[25], and role complexity[26]. The four indicators are negative, that is, the more complex the process, the lower the blockchain technology application maturity. The detailed descriptions of the indicators are shown in Table 1.

2.1.4 Application of ecological completeness

The application of blockchain technology to solve problems requires comprehensively considering the related ecological environment. In this study, the application ecology is divided into the following points: policy conditions, market conditions, infrastructure construction, and related talent reserve. Among them, policy conditions mainly consider the number of relevant policies and standards introduced by the government, and market conditions consider the number of partners needed and available to build the blockchain technology system.

Meanwhile, infrastructure construction considers the current state, whether the system meets the blockchain technology application demands, and the additional costs required to build and replenish the infrastructure in the future. Finally, the reserve of relevant talents refers to the current number of blockchain-related technical personnel and the additional costs required to train the current employees after applying blockchain technology.

The application ecological completeness measure consists of four indicators: policy conditions, market conditions, infrastructure construction, and technology-related talents. These indicators are all positive, and the more adequate the relevant conditions are, the higher the blockchain technology application maturity. The details of the indicators are reported in Table 1.

2.1.5 Technical performance requirements

As the core technology of blockchains has yet to fully mature, certain limitations in its performance exist, that is, it cannot effectively meet the three major performance requirements of high-efficiency and low-energy consumption, decentralization, and security and privacy protection simultaneously[27]. Therefore, when considering the ease of blockchain implementation, the demand for the three types of performance requirements must be considered in conjunction with the demand tendencies of specific application scenarios. The technical performance requirements measure consists of three metrics: high-efficiency and low-energy consumption, decentralization, and security and privacy protection. The descriptions of the indicators are provided in Table 1.

2.2 Calculation of index weights

In this study, a judgment matrix questionnaire is designed based on the index system of the evaluation model using the hierarchical analysis method. The questionnaire is sent to experts in related fields to obtain the judgment matrix value of the evaluation system, and the AHP subjective weight value is calculated based on this value. On this basis, the objective weight value is obtained using the entropy weight method, and the AHP subjective weight value is comprehensively revised to obtain the final weight value.

2.2.1 Calculation of subjective weights using the AHP hierarchical analysis method

According to hierarchy theory, based on the current assessment model, the value of the comparative judgment matrix is determined using the two-by-two comparison method between each index. In the hierarchical analysis method, the value of each element in the judgment matrix is generally determined using a nine-point scale, as shown in Table 2.

After the judgment matrix is obtained, a consistency test is performed by obtaining the eigenvector of the maximum eigenroot λ_{max} of the matrix as the weight vector of the corresponding index using the index consistency ratio (CR).

Table 2 AHP hierarchical analysis method.

Scale	Meaning
1	Importance between i and j is identical.
2	Importance between i and j is between Scales 1 and 3.
3	Between i and j, the former is slightly more important than the latter.
4	Importance between i and j is between Scales 3 and 5.
5	Between i and j, the former is significantly more important than the latter.
6	Importance between i and j is between Scales 5 and 7.
7	Between i and j, the former is considerably more important than the latter.
8	Importance between i and j is between Scales 7 and 9.
9	Between i and j, the former is more important than the latter.

Note: If the importance between factor i and factor j is a, then the importance between j and i is $1/a$.

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

where n is the order of the judgment matrix, and RI is the random consistency index related to the order of the matrix. The RI values are shown in Table 3.

A consistency test is performed for each judgment matrix, and the CR value of the corresponding matrix is calculated. When $CR \leqslant 0.1$, the judgment matrix is accepted; otherwise, the matrix is rejected.

In this study, 18 professionals involved in blockchain research and practice, including seven university researchers, six industry organization personnel, and five researchers in practical fields, are invited to complete the questionnaire. The questionnaire includes the definition of each indicator in the assessment model and tables comparing the importance of each indicator. The questionnaire contains five tables capturing the importance of four indicators, which are "key application requirements", "data security", "process complexity", and "application ecological completeness".

The importance score of each secondary indicator under the four primary indicators and the importance score of the five primary indicators under "blockchain application" are obtained. Among them, the first-level "technical performance requirements" indicator has a special feature in which the technology cannot simultaneously meet the requirements represented by the three

Table 3 *RI* values.

No.	*RI*
1	0
2	0
3	0.52
4	0.89
5	1.12
6	1.26
7	1.36
8	1.41
9	1.46

second-level indicators, thus, the weight of the second-level indicators is not calculated by the judgment matrix but assigned according to the number of requirements. That is, if one or two requirements exist, then the first-level indicator will be given a full score; otherwise, it will be given a score of 0.

In this study, 19 questionnaires are sent out, and 18 questionnaires are returned, 17 of which are valid. Each judgment matrix obtained from the valid questionnaires is analyzed for consistency, and the weight value assigned to each indicator by each expert is calculated based on the judgment matrix that passed the consistency test. On this basis, the AHP subjective weight value is calculated for each indicator as a unit.

2.2.2 Calculation of objective weights using the entropy weight method

The entropy method is an objective weighting method, and compared with the subjective weighting method, it excludes subjective interference factors and objectively determines the amount of information contained in the indicators. Moreover, the entropy method assigns weights to the indicators according to their degree of variability, which is widely used for economic indicators. The basic idea behind the entropy weighting method is to determine the objective weight according to the variability of the indicators. Calculating the information entropy of the index shows that the smaller the information entropy, the greater the variability of the index, the more information it contains, the greater the role it can play in the corresponding evaluation system, and the greater the weight of the index in the evaluation system.

The information entropy E_j is calculated as follows:

$$E_j = -\ln(n)^{-1}\sum_{i=1}^{n} p_{ij}\ln p_{ij} \tag{3}$$

When its approximate logarithm is taken,

$$E_j = -\ln \textstyle\sum_{i=1}^{n} p_{ij}\log_n p_{ij},\ p_{ij} = \dfrac{y_{ij}}{\sum\limits_{i=1}^{n} y_{ij}},\ p_{ij}\ln p_{ij} = 0 \tag{4}$$

On the basis of the indicator weight values provided by the various experts, after the information of each indicator is derived, the objective indicator weight values of the entropy weight method are obtained from Eq. (5).

$$W_i = \frac{1-E_i}{n-\sum E_i} \tag{5}$$

2.2.3 Comprehensive index weights

Based on the objective and subjective weight values obtained using the above two methods, the Euclidean distance is introduced to calculate the composite weights[21].

$$\begin{cases} W_j = \alpha w_{Aj} + \beta w_{Bj}, \\ \alpha + \beta = 1 \end{cases} \tag{6}$$

where α and β are the subjective and objective weight coefficients, respectively. The calculation procedure is shown in Eq. (7).

$$\begin{cases} D(w_{Aj}, w_{Bj}) = \sqrt{\sum\limits_{j=1}^{n}(w_{Aj} - w_{Bj})^2}, \\ D(w_{Aj}, w_{Bj})^2 = (\alpha - \beta)^2 \end{cases} \tag{7}$$

The final calculated combined weight values are listed in Table 4.

Table 4 Comprehensive index weights.

	Indicator	Weight
Primary	Key application requirements	0.230 301
	Data security	0.226 036
	Process complexity	0.165 296
	Application ecological completeness	0.209 872
	Technology performance requirements	0.168 495
Secondary	Data ledger complexity requirements	0.299 203
	Data authenticity requirements	0.459 282
	Large-scale consensus requirements	0.241 516
	Degree of data source monitorability	0.335 750
	Data source trustworthiness	0.318 915
	Data flow reliability	0.345 335
	Number of process activities	0.269 234
	Control flow complexity	0.227 464
	Data complexity	0.245 507
	Role complexity	0.257 795
	Policy conditions	0.312 293
	Market conditions	0.281 071
	Technology infrastructure	0.210 96
	Relevant talent status	0.194 976
	High-efficiency and low-energy consumption	—
	Decentralization	—
	Security and privacy protection	—

2.3 Typical project evaluation and analysis

2.3.1 Project evaluation questionnaire design

To assess the maturity of blockchain technology applications in digital government public service projects, this study uses a questionnaire to obtain the scores of actual projects from blockchain technology experts and adopts the scoring method of the experts to assess the blockchain technology application maturity. The questionnaire comprises two parts. The first part is the project profile, including information on the four aspects of the project, that is, the application scenarios, participating organizations, application profiles, and solution pain points. The second part presents the scoring rule tables for each indicator (Table 4). The logic of the questionnaire design is that the higher the indicator score, the higher the blockchain technology application maturity.

After obtaining the experts' scores for the secondary indicators of each project, the scores of each primary indicator are calculated by combining the indicator weights of the evaluation system and converting the results into a percentage system. Based on the final percentage score, the overall project score is calculated.

As the four second-level indicators under "process complexity" are negative, they must be processed as follows:

$$score_1 = 8 - score_0 \tag{8}$$

In addition, the three second-level indicators under "technical performance requirements" use a dichotomous system. That is, 1 indicates that the condition is satisfied; 0, not satisfied. When the sencondary indicators under " technical performance requirements" score greater than or equal to 1 or less than or equal to 2, the first-level indicator receives a full score; otherwise, 0 point.

2.3.2 Comprehensive assessment and analysis of typical projects

In this study, ten digital government public service projects applying blockchain technology are selected, and the specific project names and numbers are shown in Table 5. The projects cover national, county, and city levels, including digital government public service projects for the public, enterprises, and government departments, which are projects that have been implemented on the ground. Pilot projects are also selected in this study for additional discussions. Pilot projects tend to differ from general landed implementation projects in that they are shorter in duration, broader in scope, and typically serve the primary purpose of testing feasibility.

The research content of this paper involves digital government and blockchain technology, therefore, 19 professionals who are engaged in blockchain research and practice and have a digital government-related research background and practical experience were invited to fill out the questionnaire. Among them, seven are from universities, including researchers from Tsinghua University, Central University of Finance and Economics, Renmin University of China, and Southwest University of Finance and Economics; six are from relevant industry research institutions, including experts from the Ningxia Blockchain Association, Shared Finance, the Zero One Finance Blockchain Group, the China Blockchain Think Tank, the Inno Angel Fund, and Firepower University; six are from the field of practice, including the China Academy of Information and Communication Research, Shenzhen Zhixing Ltd., the China Information Security Testing and Evaluation Center, and the Shandong Blockchain Research Institute.

In the process of inviting them to score, we provided a detailed introduction to the ten projects, including information on application scenarios, participating organizations, project profiles, and pain points solved. We also provided the experts with a scoring sheet (1–7 scale) with detailed indicators and indicator descriptions, and the experts were required to score each of the 17 secondary indicators. According to the survey statistics, after the questionnaires were returned, we found that each expert needed approximately 30 min to complete the questionnaire.

The project profiles and scoring details were sent as a questionnaire to 18 academic and practical blockchain technology experts, along with the content of Table 5. A total of 19 questionnaires were sent out, and 18 valid questionnaires were returned. The scoring results of the 18 experts for the 10 digital government public service projects applying blockchain technology were collected. Based on the scores of each secondary index, the total score of each project was obtained by combining the corresponding weights, and the scores were converted into percentages. For each project, the arithmetic mean of the total score of each expert was calculated, and results similar to those in Table 6 were obtained.

The results in Tables 5 and 6 show that the final scores of all ten selected projects exceed 60 points, that is, they exceed the passing score in the general sense of the percentage system and belong to projects with practical value and application value, which have been implemented on the ground, consistent with the scoring results. This finding indicates that applying blockchain technology in digital government public service projects is highly feasible and can improve government services and government work efficiency.

3 Result and Discussion

3.1 Analysis of indicator weights in the assessment model

3.1.1 Analysis of the importance of first-level indicators

According to the experts' scores, the weighting of the first-level indicators from highest to lowest is "key application requirements", "data security", "application ecological completeness", "technical performance requirements", and "process complexity". Based on this result, when the maturity of the blockchain technology project application is evaluated, priority should be given to whether the key requirements of the application scenario are consistent with the functions that blockchain technology can provide. The more consistent they are with the requirements, the higher the value of applying blockchain technology is, and the more mature the conditions for applying blockchain technology are. In addition, the higher the degree of data security and control, the higher the maturity of the blockchain technology application. Furthermore, whether the current ecological environment of the blockchain technology application supports it should be considered. The maturity of the blockchain technology application is high if the performance limitation is not exceeded. Finally, the complexity of the activity process involved in the application scenario must be considered, and the more concise and clear the process, the higher the maturity.

Table 5 Blockchain technology application in typical digital government public service projects.

Type	No.	Project name
Beneficiaries of public services (for individuals and companies)	1	Beijing Municipal Financial Supervision Bureau's blockchain-based enterprise electronic identity authentication information system
	2	Blockchain-based financial service platform for small and medium-sized enterprises in the Haidian District, Beijing
	3	Beijing Municipal Bureau of Commerce Airport International Logistics Blockchain Platform
	4	Huafa Lyre-IPTM time mark one-stop intellectual property service platform
	5	Blockchain-based real estate registration system of the Beijing Municipal Planning and Natural Resources Commission
	6	Construction of the Langfang Education Data Monitoring Platform Project
Public service providers (for the government)	7	The State Administration of Taxation Shenzhen Municipal Taxation Bureau Blockchain Natural Person Information Sharing Smart Platform Project
	8	Beijing Economic and Technological Development Zone Government Affairs Work Chain Platform
Pilot project	9	Blockchain application pilot in the field of government services in the Haidian District
	10	Blockchain application pilot in the field of government services in the Shunyi District

Table 6 Scoring ranking of blockchain technology application in typical digital government public service projects.

No.	Score	Rank
1	70.040 95	4
2	70.206 75	3
3	67.500 10	8
4	65.818 58	10
5	70.486 34	1
6	67.585 62	7
7	67.033 19	9
8	70.333 92	2
9	69.548 09	5
10	67.684 19	6

3.1.2 Analysis of the importance of secondary indicators

For the first-level "key application requirements" indicator, priority should be given to whether the project application scenario has high requirements for data authenticity, followed by requirements for the complexity of the ledger data and requirements for a large-scale consensus. For the first-level "data security" indicator, the experts pay more or less equal attention to the degree of data source trustworthiness, data source monitorability, and data flow reliability. For the first-level "application ecological completeness" indicator, when applying blockchain technology, priority should be given to whether the policy conditions are met, followed by whether the market conditions are met, and finally, to the technical infrastructure and related talents. For the first-level "process complexity" indicator, the four second-level indicators receive approximately the same degree of concern and can be evaluated in the following order: number of process activities, role complexity, data complexity, and control flow complexity.

3.2 Evaluation analysis of digital government public service projects for individuals and enterprises

3.2.1 Evaluation analysis of individual-oriented digital government public service projects

For the public service projects for individuals and enterprises (Projects 1–6), three projects (Project 2, Project 6, and Project 4) with large differences in ranking and significant differences in the scores of the primary indicators are selected as typical projects for the analysis based on their ranking after the expert score deviations are standardized. The selected projects are the Beijing Haidian District Blockchain-Based Financial Service Platform for SMEs (Project 2: project rank 3 and project rank 1 after deviation standardization), the Langfang Education Data Monitoring Platform Construction Project (Project 6: project rank 7 and project rank 6 after deviation standardization), and the Huafa Seven Strings–IPTM time-marked one-stop IP service platform (Project 4: project rank 10 and project rank 9 after deviation standardization). The following conclusions are obtained.

Projects 2 and 4 mainly differ in their scores for "data security", "application ecological completeness", and "technical performance requirements". Because of the specificity of the "technical performance requirements" index, it was not analyzed, and only the impact of the differences between "data security" and "application ecological completeness" is considered. According to the project background survey, Project 2 mainly builds financial service platforms to provide financial services to SMEs in the Haidian District of Beijing, whereas Project 4 mainly provides copyright protection-related services to individual creators. As the enterprise must be regulated by the government, the data source of Project 2 is highly credible and controllable, thus, it obtains a high "data security" score. In addition, the ecological environment of Project 2 differs from that of Project 4. As relevant government departments are involved in guiding the promotion of Project 2, the scores of "ecological environment" and "application ecological completeness" are highly complete. The difference between the two projects ultimately affects their overall ranking.

The scores of Project 2 and Project 6 differ greatly because all the indicators of Project 2 are higher than those of Project 6 except for "technical performance requirements". However, Project 6 scores higher than Project 2 and the highest among the ten projects on the "technical performance requirements" indicator. This outcome is observed because the main application scenarios of Project 6 are electronic evidence storage, electronic identity authentication, credit management, qualification proof, copyright protection, and so on. Furthermore, the main service targets are teachers and students, and the main function of Project 6 is to store students' file information through blockchain technology, establishing students' growth files, using the education system to form objective evaluations of the students' growth process, and building an education system of integrity. On this basis, the system's blockchain technology performance demand is focused on "decentralization" and "security and privacy protection". Therefore, Project 6 satisfies the conditions for obtaining a high score in the first-level "technical performance requirements" indicator.

3.2.2 Evaluation analysis of government-oriented digital government public service projects

For the government-oriented projects (Projects 7 and 8), that is, the blockchain natural person information sharing intelligence platform project of the Shenzhen Taxation Bureau of the State Administration of Taxation (Project 7: project rank 9 and project rank 10 after deviation standardization) and the government work chain platform of the Beijing Economic and Technological Development Zone (Project 8: project rank 2 and project rank 4 after deviation standardization), the following conclusions are drawn.

The gap between the two projects is mainly reflected in the first-level "technical performance requirements" indicator. Because of the special characteristic of this indicator, a large gap can be observed in the final ranking of the two projects, that is, when a project has a demand or no demand for the three secondary indicators of blockchain technology performance, the score of the first-level indicator is full, resulting in a large gap.

Apart from the "technical performance requirements" indicator, the scores of the other two indicators are relatively close. Project 8 scores much higher than Project 7 on "process complexity", and the project survey shows that the main application scenarios of both projects involve data sharing and exchange and serving internal government departments. The difference between the two projects is the number of government departments involved, which, in Project 8, is seven that are mostly related to the economic sector. Project 7 involves a total of 11 municipal-level collaborative governance group member units, and the data on the chain include various types of tax-related information on topics such as education, health, and medical insurance. In addition, Project 8 designed two different platforms, that is, a service platform and a management platform, according to different user roles, thereby separating the specific services it provides based on different user rights and purposes and clarifying the overall structure. In contrast, Project 7 makes no such distinctions. Thus, Project 7 is ranked much lower than Project 8.

3.2.3 Evaluation analysis of pilot projects

For the blockchain technology application pilot projects (Projects 9 and 10), that is, the blockchain technology application pilot projects in the field of government services in the Haidian and Shunyi Districts. The following conclusions are drawn.

Both projects are district-level blockchain technology application pilots in Beijing, thus, their overall scores and rankings are similar. Most of their first-level indicators are similar, but a difference is observed in the "process complexity" indicator, with Project 9 scoring lower than Project 10. The main reason for this outcome is that Project 9 involves various types of data and has a large scope, including seven types of national data, 20 types of municipal data, four types of district data, and nearly 300 data necklaces on applications such as resident ID cards and household registration books. The large and complex data volume and data types add to the complexity of the application, thereby resulting in a low score for the "process complexity" indicator.

In terms of the overall scores of the ten projects, the two application pilot projects show high scores on the two first-level indicators of "key application requirements" and "data security", which are commonly used in data sharing and exchange, business collaboration, and electronic document storage and licensing. Blockchain technology can provide effective solutions for the above scenarios. Data security can be guaranteed to a certain extent because the relevant data are regulated by the relevant departments. In addition, as both projects involve the pilot operation of the application scenarios, their processes are complex, thus, their first-level " process complexity" indicator scores are generally lower than those of the other projects. The final results show that the overall rankings of the two pilot projects are intermediate.

4 Conclusion and Insight

4.1 Conclusion

Based on the existing literature, this study proposes a blockchain application maturity assessment system consisting of five first-level indicators and corresponding second-level indicators, combined with the characteristics of blockchain application scenarios and technical features of digital government public services; then the AHP-entropy weight method and expert scoring method are used to determine the corresponding weights of each indicator in the assessment system, and a blockchain application maturity assessment method is constructed. The evaluation weights of the five primary indicators of blockchain application maturity, namely, application critical requirements, data security, application ecological completeness, technical performance requirements, and process complexity, are from high to low. The evaluation weights of several secondary indicators are close to each other, while the important secondary evaluation indicator of "application critical requirements" is " data authenticity requirements"; the important secondary evaluation indicator of "application ecological completeness" is "policy". The important secondary evaluation index in " application ecological completeness" is "policy conditions".

On this basis, this study applied the method to 10 typical digital government public service projects and found that "data security" and " application ecological completeness" are the key factors affecting the maturity of blockchain applications in projects for individuals and enterprises. In government-oriented projects and pilot projects, "technical performance requirements" and "process complexity" are the key factors affecting the maturity of blockchain applications.

4.2 Management insights

Based on the "Blockchain White Paper" of the China Academy of Information and Communication Technology and related literature on blockchain research, as well as in-depth interviews with experts, this study constructs a blockchain technology application maturity assessment model for digital government public services and assesses and analyzes typical projects to explore the key features affecting blockchain technology application maturity, which can provide a theoretical basis for applying blockchain technology to improve the implementation effect of digital government public service projects.

First, this study focuses on matching the key requirements of application scenarios with blockchain technology. Developing and applying blockchain technology requires a large amount of financial and human capital, as the process of applying blockchain technology to address the inefficiency of traditional digital government public services generally involves certain tradeoffs. According to the comprehensive weights of the indicators in the index system established in this study, the "high-value" factor is the key to evaluating blockchain technology application maturity.

Therefore, we should focus on the key requirements of an application scenario and its matching degree with blockchain technology rather than on the complexity of the overall project process to avoid overexploitation and repeated construction. Management should also focus on investing increased resources and efforts on projects with high application needs to achieve improved results.

Second, "low-risk" is an important prerequisite for blockchain application maturity. Data security before the data are chained, that is, the controllability and trustworthiness of the data source and data flow process security, will considerably affect the efficiency of the data chaining and synchronization. The projects with high overall scores focus on data security supervision and control. If data security is low, the effect of the blockchain technology application will be diminished. In the government, some data are highly confidential and may entail serious consequences if tampered with or lost. Therefore, special attention should be paid to data security to realize data closed-loop security in front of and on the chain and the synergistic development of blockchain technology and big data technology.

Third, clarifying the key needs of application scenarios for blockchain technology is essential. The project scores and rankings obtained by this study show that the projects with low scores are generally those with broad application scenarios involving numerous units and using large amounts of data.

Therefore, in the project planning and management process, the service targets should be clarified, the user roles should be classified, and the different functions should be divided according to the different identities of the users. Before deciding on applying blockchain technology to solve problems, the key requirements of blockchain technology in different service scenarios should first be identified. The tradeoff between "high-efficiency and low-energy consumption", "decentralization" , and " security and privacy protection" should be analyzed to achieve differentiated and personalized applications.

4.3 Limitation

The limitations of this study include two main aspects.

First, the project cases used in this study have been implemented, the descriptions were derived from the Internet, and the scores were subjectively determined by the selected experts, thus, the final system weights and scores are subjective and limited. In addition, as few relevant studies are available on the maturity of blockchain technology application in digital government public service projects, the weights and scores cannot be compared with those of other evaluation index systems to illustrate the scientific nature of the evaluation method introduced in this study.

Second, because of the specificity of the "technical performance requirements" indicator, the scoring method used in this study is imperfect and should be improved in subsequent studies. Meanwhile, the inconsistency of blockchain technology algorithms and structures for digital government public service projects in different regions and departments can hinder the unification of the evaluation caliber. Therefore, in the practical application process, the evaluation index weights suitable for specific project application scenarios as well as the final scores should be calculated by combining the specific application scenarios and previous data, which should be used to judge whether blockchain technology should be used to solve the current problems.

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