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Research Article

Blockchain-Based Intelligent Transportation: A Sustainable GCU Application System

Xiaomin Du,[1] Yang Gao,[2] Chia-Huei Wu,[3] Rong Wang,[2] and Datian Bi [4]

[1]*Department of Economic Management, Yingkou Institute of Technology, Yingkou, China*
[2]*School of Economics and Management, Dalian University of Technology, Dalian 116024, China*
[3]*Institute of Service Industries and Management, Minghsin University of Science and Technology, Hsinchu 304, Taiwan*
[4]*School of Management, Jilin University, Changchun 130022, China*

Correspondence should be addressed to Datian Bi; bdt@jlu.edu.cn

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The purpose of this study is to explore how to apply blockchain technology to intelligent transportation, create a hierarchical theoretical framework of intelligent transportation, and explore a sustainable application system of intelligent transportation under the blockchain. However, not only this hierarchical theoretical framework must consider unnecessary attributes and the interrelationships between the aspects and the criteria, but also the sustainable application system must be in consideration in multiple stakeholders. Hence, fuzzy set theory is used for screening out the unnecessary attributes, a decision-making trial and evaluation laboratory (DEMATEL) is proposed to manage the complex interrelationships among the aspects and attributes, and interpretive structural modeling (ISM) is used to divide the hierarchy and construct a hierarchical theoretical framework. Finally, the research develops a sustainable GCU application system for intelligent transportation under the blockchain. The results show that (1) solving social problems is the primary link, (2) economic tasks are mainly focused on smart contracts and affected by the social problems, (3) the continuous improvement of environmental issues requires a solution to social problems, and (4) the application system of blockchain in intelligent transportation needs to be built from three levels including the government layer, the company layer, and the user layer. This theoretical hierarchical framework aims to guide intelligent transportation toward the application of blockchain. This study also proposes the engagement of stakeholders for establishing a sustainable application system.

1. Introduction

Urban intelligent traffic aims to give full play to the carrying capacity of the road network, solve all varieties of traffic problems, and improve traffic safety and environmental protection. In the field, this means using physics, computer science, Internet of Things technology, and integrated traffic information to establish a dynamic information service system to realize a rapid response to traffic problems, improve traffic conditions, and increase transport efficiency [1, 2]. Intelligent transportation will greatly improve the management of urban transportation systems to optimize the urban layout and promote the process of smart city development [3]. Blockchain, as a disruptive technological innovation following the emergence of the Internet, is being applied for its tamper-proof, traceable, high-trust, and decentralized distributed accounting system [4, 5], leading to a new round of global technological and industrial changes. Combining blockchain and intelligent traffic to establish a transportation consortium blockchain participated in by government, company, and user, allowing implementation of data upload, storage, and conditional queries, will promote the further upgrade and development of intelligent transportation.

Currently, blockchain has attracted wide attention from all walks of life. Existing research results include the basic underlying technologies of blockchain [6, 7], blockchain credit evaluation systems [8], and blockchain transaction cost analysis [9, 10]. However, studies on blockchain in the intelligent transportation industry are still in the exploratory stage, and most focus on the impact of the characteristics of blockchain on transportation, such as the establishment of blockchain-based traffic safety data sharing systems [11], the creation of electric vehicle safe energy trading schemes [12, 13], or the issue of freely tradable mobile licenses based on the blockchain [14]. The development system for intelligent transportation under blockchain is very vague. In addition, the application of blockchain in the intelligent transportation industry is difficult to explain from a single level because it interacts with all the subjects in intelligent transportation simultaneously in the application process, requiring multiple subjects to cooperate and interact with each other. From the perspective of stakeholders, it is still rare to explore a development system coordinated by multiple subjects. Moreover, few existing studies have studied the combination of blockchain and intelligent transportation from a sustainability perspective, which requires comprehensive consideration of upgrading needs and challenges for intelligent transportation brought by blockchain considering three aspects: the economy, society, and environment. Finally, at present, the application of blockchain to the physical industry lacks exploration at the level of consortium blockchains, as research is more focused on private blockchains [15]. Due to the existence of information controlled by the leading enterprise, the credibility of information is questioned in private blockchains, and their application is limited [16]. Although public blockchains have greater information credibility than private blockchains, they remain difficult to apply and popularize in the real economy. This is because the public blockchain needs to include a large number of participants, making it difficult to guarantee the security of participant's privacy [17], and blockchain's feature of "complete decentralization" brings great obstacles to the system design. By featuring only "partial decentralization," the consortium blockchain just needs to include a limited number of subjects to increase security, reduce cost, increase reliability, and increase the level of trust in the application process to better control and promote the implementation of blockchain in intelligent transportation.

Urban transportation includes a wide range. Considering that underground transportation has its unique operating system such as the subway. Our research focuses on urban ground transportation, including buses, private cars, taxis, and Internet-based traffic. Based on the above, to develop a sustainable application system of blockchain in intelligent transportation based on a consortium blockchain, the following research is carried out in this paper. First, to systematically consider the impact of blockchain on the sustainable development of intelligent transportation, a set of valid criteria are proposed from the three aspects of the economy, society, and environment. Second, considering the mutual restriction and in order to make multiattribute decisions among multiple attributes, the theory of fuzzy sets, decision-making trial and evaluation laboratory (DEMATEL), and interpretation structure model (ISM) are synthetically integrated. Third, combined with the above analysis and the theory of stakeholders, a sustainable application system of blockchain intelligent transportation based on a consortium blockchain is constructed from the three levels.

Through this study, we can draw the following scientific conclusions. First, the impact of blockchain technology on the sustainable development of intelligent transportation is mainly reflected in three aspects, namely, the social level, economic level, and environmental level. Second, the study finds that these three layers have different importance. First, solving social problems is the primary link for the sustainable development of blockchain in intelligent transportation. At the social level, we need to solve two problems: institutional completeness and the impact of blockchain technology characteristics on society. Second, in the whole development process of blockchain in intelligent transportation, the development of the economic level mainly occurs around smart contracts and is affected by the social level. The continuous improvement of environmental issues requires a solution to social problems. In addition, one innovation of this paper is its study of the related issues in the field of blockchain-based intelligent transportation from the perspective of finance and taxation. Finally, the application system of intelligent transportation under the blockchain needs to be built around three levels: the government layer, the company layer, and the user layer. The results of this paper provide an important theoretical reference for the sustainable development of intelligent transportation under the blockchain.

2. Literature Review

As the underlying technology of bitcoin, the blockchain is essentially a decentralized database that comprehensively utilizes distributed data storage, consensus mechanisms, point-to-point transmission, encryption algorithms, intelligent contracts, and other computer technologies. Data with timestamps and digital signatures are packaged into blocks in the blockchain, which are linked by hash pointers to form a chained ledger structure. The distributed storage of the blockchain facilitates data sharing, and the digital signature in the data records can self-verify the correctness of the data. By linking blocks together, hash pointers prevent hackers from falsifying the data and allows the data to be traced back to its source. The technological novelty of blockchain lies in the fact that it is possible to build a consensus on the true state of the ledger without trusting any centralized entity or an intermediary [18]. Therefore, the blockchain has the excellent characteristics of supporting data sharing and being tamper-proof, trustworthy, and traceable, making it suitable for building an information system to deal with multiparty collaborative business.

By applying blockchain technology to intelligent transportation, our research has built a transportation consortium blockchain led by the government and involving multiple parties, giving full play to the carrying capacity of the road network, solving various traffic problems, and improving traffic safety and environmental protection. In this study, we analyzed the economic, social, and environmental aspects of the system based on the triple bottom line principle. The economic focus is on cost analysis, the social aspect focuses on the management of social issues, and the environmental aspect mainly refers to the environmental benefits of blockchain-based intelligent transportation. Combined with new technologies such as the Internet of Things and the characteristics of blockchain, the application system of blockchain in intelligent transportation is built, including 3 aspects and 15 criteria.

2.1. Intelligent Transportation under Blockchain: Economic Aspect. In terms of the economy, we begin with a cost analysis to study the impact of blockchain-based intelligent transportation on the economic cost of government and enterprises. The four criteria include transaction cost, management cost, infrastructure construction cost, and financial cost.

Blockchain, which keeps a permanent record of past transactions and has a tamper-proof system, can reduce well-designed opportunistic behavior. Reliable ledgers can create an economic environment with low transaction cost, which is a prerequisite for achieving economic efficiency and prosperity [19]. Intelligent contracts and information sharing technology can establish a better trust mechanism that can reduce the behavioral uncertainty in the transaction relationship. The distributed accounting system and decentralized nature of blockchain reduce the costs associated with intermediaries. All these factors reduce the transaction cost of government and enterprises [9, 10]. In terms of management cost, automatic data uploading and traceability systems can reduce the cost of monitoring, controlling, and approving the fund flow to prevent fraud and increase the supervision of the fund flow. Immutable and distributed bookkeeping reduces the human cost of information research, monitoring, and management for governments and enterprises [20]. The use of smart contracts can reduce the use of paper and other consumables, realize rapid discussion, and save time, and sharing databases can reduce management work [21]. In terms of infrastructure construction cost, traffic information in the blockchain can be analyzed and processed to support the overall planning of the urban traffic network layout, including logistics and transportation, road planning, road construction, bus station construction, and optimization of the supporting infrastructure construction scheme. In terms of financial cost, the automatic data uploading and traceability system facilitates the electronic bill management of companies. Blockchain technology gives the government and auditing institutions the right to examine company accounts through blockchain, strengthens the supervision of company profits and taxes, and reduces tax fraud. Coyne and McMickle [22] believe that blockchain-based digital currency only exists in the blockchain, while economic transactions exist outside the blockchain records, which will prevent the use of the blockchain model for acceptable transaction verification. However, combining blockchain with the Internet of Things technology can effectively solve this problem and make blockchain accounting possible in the field of transportation.

2.2. Intelligent Transportation under Blockchain: Social Aspect

2.2.1. Blockchain Features Have an Impact on Society. Blockchain is a distributed shared ledger and database involving mathematics, cryptography, the Internet, computer programming, and other fields. It has the characteristics of being decentralized, tamper-proof, and traceable and supporting whole-process marking, collective maintenance, openness, and transparency [23]. These features ensure the reliability of the blockchain. The combination of blockchain and the Internet of Things technology can realize automatic data upload and timely information update, which can improve the timeliness of transactions by instantly forming smart contracts [24]. Therefore, we classify the characteristics of blockchain as reliability and timeliness.

2.2.2. Problem Management. In this section, we discuss how the blockchain can optimize solutions to the existing problems in traffic, relieve traffic pressure, and promote urban development, including Internet-based traffic management, congestion management, urban space optimization, convenient travel, and parking management as 5 criteria.

In terms of Internet-based traffic management, blockchain technology allows the use of the aggregate signature scheme to connect the channels under the chain to build a secure large-scale real-time payment system and improve the capacity of the blockchain system [25]. The blockchain is used to record Internet-based traffic information and make public the basic personal information and credit ratings of Internet-based traffic drivers to ensure that those responsible for traffic accidents can be held accountable. At the same time, transaction information for Internet-based traffic can be tracked and conditions investigated, which will make it easier for the government to collect taxes and facilitate tax administration.

In terms of congestion management, solutions to alleviate traffic congestion are as follows: the traffic management department issues a limited number of mobile licenses, distributes them equally among all users, and conducts free trade in the market through blockchain technology and "smart contracts" [14]; priority is given to emergency vehicles by allocating high prices on all routes; in the "Internet of vehicles" environment, the data exchange between vehicles and between vehicles and infrastructure is regarded as transaction information stored in the blockchain to enrich the traffic information; heavy truck rows are encouraged [26]; payment is made in blockchain digital currency to reduce transaction time [27]; machine vision technology is used to collect the images of relevant sections, solve the problem of image recognition in intelligent vehicles, optimize the judgment of obstacles, and plan the follow-up routes of intelligent vehicles [28].

In terms of urban space optimization, regional industrial agglomeration promotes the optimization of urban structure and space and promotes the sustainable transformation of cities, which in turn will promote the optimization of transportation networks [3]. In terms of convenient travel, users are encouraged to participate in the blockchain platform to share traffic information and improve navigation information. At the same time, the reduction of traffic congestion and the convenience of public transportation will facilitate public travel. In terms of parking management, free parking can be traded through the blockchain, which can generate income for the owner, on the one hand, and alleviate the problem of difficult parking, on the other hand.

2.2.3. Top-Level System Design. The top-level system design, including the reward and punishment system and the credit evaluation system, is the foundation of the whole blockchain-based intelligent traffic index framework and plays an important supporting role in the system. The reward and punishment system refers to virtual currency rewards for users who actively participate in blockchain and publish real information [29]. A credit evaluation system refers to the use of blockchain technology to ensure data integrity and nonrepudiation, evaluate user trust by evaluating service trust, behavior trust, and task trust, and establish a safe and reliable database to support analytical queries with different query timestamps [8, 11]. Yang et al. [30] proposed a blockchain-based decentralized trust management system for vehicle networks.

2.3. Intelligent Transportation under Blockchain: Environmental Aspect. The most serious part of urban traffic pollution is the excessive emission of automobile exhaust. Methods to reduce urban traffic pollution through blockchain include optimizing traffic routes through blockchain, reasonably controlling speed; reducing instantaneous acceleration and idling to reduce carbon dioxide emissions [31, 32]; and encouraging or requiring heavy truck lines to reduce air resistance and fuel consumption [33]. The popularity of energy transactions between electric vehicles and charging stations in the vehicle-to-grid (V2G) environment has increased the use of electric vehicles [12, 13]. A more comprehensive public transport system has increased the rates of public travel. In addition, a reasonable urban greening layout based on multiple pieces of information in the transportation consortium blockchain [34] is also beneficial to urban environmental governance. A detailed explanation of each criterion is shown in Table 1.

3. Method

This paper uses the DEMATEL method to fully consider the number and correlation of influencing factors and gives the importance of the influencing factors. We explore from 15 influencing factors and explain the inner structure of the influencing factor system in a deeper level, including transaction cost (C1), management cost (C2), infrastructure construction cost (C3), financial cost (C4), reliability (C5), timeliness (C6), Internet-based traffic management (C7), congestion management (C8), urban space optimization (C9), convenient travel (C10), parking management (C11), reward and punishment system (C12), credit evaluation system (C13), urban traffic pollution (C14), and urban greening layout (C15). Considering the complexity and ambiguity of the relationship between various influencing factors, this paper introduces the concept of fuzzy sets and uses a semantic conversion table to perform a series of transformations on the original expert data to remove subjective factors. The hybrid DEMATEL method is used to standardize the hybrid matrix given by the experts and obtain a hybrid comprehensive influence factor matrix by matrix calculation. Then, calculate its centrality and causality to reveal the most critical factors affecting the blockchain-based intelligent transportation [35]. The DEMATEL method can calculate the importance of a specific factor in the influencing factor system, but it cannot determine the intrinsic relationship of the factors and the division of the hierarchical structure. It is difficult to effectively manage and control the factors. Therefore, the ISM method is also required to classify the system structure. And the combination of the two methods can reduce the difficulty in matrix calculation [36]. The ISM method can transform nebulous thoughts and ideas into an intuitive model of structural relationships to understand the relationship between the variables [37].

3.1. Fuzzy DEMATEL. Fuzzy mathematics based on fuzzy set theory is applied to the analysis of the fuzzy degree of feature relevance. Triangular fuzzy number (TFN) provides an effective means of quantifying human linguistic preferences into computable form [38]. DEMATEL technique provides a way to elucidate the complex interrelationships among attributes in a given problem [39]. Fuzzy DEMATEL is a method to simulate the human brain processing fuzzy information [40]. This method retains practical and effective advantages of the traditional DEMATEL method for factor identification. In addition, the triangular fuzzy number is used to replace the original accurate value, and this approach can improve the credibility of the analysis results and provide a more valuable reference for managers to make decisions. The steps are as follows [41]:

Step 1: for the problem under study, build a system of influencing factors set to $F1, F2, \ldots, Fn$.

Step 2: determine the influence relationship between two factors by an expert scoring method and express the relationship in matrix form. Invite experts to use the language operators "no impact (N)," "very low influence (VL)," "low influence (L)," "high influence (H)," and "very high influence (VH)." The relationship between the two factors is assessed. Convert the original expert evaluations into triangular fuzzy numbers via a semantic table $w_{ij}^k = (a_{1ij}^k, a_{2ij}^k, a_{3ij}^k)$ to represent the extent to which k experts consider the influence of the i-th factor on the j-th factor, as shown in Table 2.

Step 3: using the Converting the Fuzzy data into Crisp Scores (CFCS) method to defuzzify the initial values of

Table 1: Proposed attributes.

Aspects	Criteria	Explanation
Economic	C1: transaction cost	Smart contracts; decentralized, tamper-proof, permanent records
	C2: management cost	Automated data upload and traceability systems reduce monitoring costs and labor costs
	C3: infrastructure construction cost	Analyze and process traffic information and plan traffic network
	C4: financial cost	Electronic bill management, blockchain-based audit, blockchain-based tax supervision
Society	C5: reliability	Secure databases, irreversibly distributed accounting systems, traceability, smart contracts
	C6: timeliness	Instantly form a smart contract
	C7: Internet-based traffic management	Blockchain accounting; record transaction information to ensure accountability for drivers
	C8: congestion management	Issue of transportation permits. Give different prices to different roads. Heavy trucks line up. Blockchain transactions
	C9: urban space optimization	Regional industrial agglomeration promotes the optimization of urban space
	C10: convenient travel	Traffic congestion is reduced, public transportation is more convenient, and traffic information is more abundant
	C11: parking management	Trade parking spaces that are not used for a period of time via the blockchain
	C12: reward and punishment system	Virtual currency rewards are offered to users who actively participate in blockchain and publish real messages
	C13: credit evaluation system	Conduct credit assessments for blockchain participants
Environment	C14: urban traffic pollution	Reasonable control of speed, reduce carbon dioxide emissions, and reduce fuel consumption; charging electric cars is easier; improve public transport
	C15: urban greening layout	Make a reasonable greening plan according to the city layout

Table 2: Semantic transformation table.

Linguistic variables	TFN
N (no influence)	(0, 0, 0.2)
VL (very low influence)	(0, 0.2, 0.4)
L (low influence)	(0.2, 0.4, 0.6)
H (high influence)	(0.4, 0.6, 0.8)
VH (very high influence)	(0.8, 1, 1)

the expert scores, the nth order directly affects the matrix Z, and the direct influence matrix reflects the direct effect between the factors, including the following four steps:

(1) Normalize triangular fuzzy numbers:

$$xa_{1ij}^{k} = \frac{\left(a_{1ij}^{k} - \min a_{1ij}^{k}\right)}{\Delta_{\min}^{\max}},\quad xa_{2ij}^{k} = \frac{\left(a_{2ij}^{k} - \min a_{1ij}^{k}\right)}{\Delta_{\min}^{\max}},\quad xa_{3ij}^{k} = \frac{\left(a_{3ij}^{k} - \min a_{1ij}^{k}\right)}{\Delta_{\min}^{\max}}. \tag{1}$$

$$xls_{ij}^{k} = \frac{xa_{2ij}^{k}}{1 + xa_{2ij}^{k} - xa_{1ij}^{k}},\quad xrs_{ij}^{k} = \frac{xa_{3ij}^{k}}{1 + xa_{3ij}^{k} - xa_{2ij}^{k}}. \tag{2}$$

$$x_{ij}^{k} = \frac{\left[xls_{ij}^{k}\left(1 - x\, ls_{ij}^{k}\right) + xrs_{ij}^{k} x\, rs_{ij}^{k}\right]}{\left[1 - xls_{ij}^{k} + xrs_{ij}^{k}\right]},\quad z_{ij}^{k} = \min a_{1ij}^{k} + x_{ij}^{k} \times \Delta_{\min}^{\max}. \tag{3}$$

$$z_{ij}^{k} = \frac{z_{ij}^{1} + z_{ij}^{2} + \cdots + z_{ij}^{k}}{n}. \tag{4}$$

Step 4: normalize the direct influence matrix Z to obtain the standardized direct influence matrix G:

$$\lambda = \frac{1}{\max\limits_{1\le i\le n} \sum_{j=1}^{n} z_{ij}}, G = \lambda Z. \tag{5}$$

Step 5: according to $T = G + G^2 + \cdots + G^n$ or $T = G(E - G)^{-1}$, E is the identity matrix, and the comprehensive influence matrix T is obtained.

Step 6: analyze the comprehensive matrix to reveal the internal structure of the sustainable application system. The elements in matrix T are added by row as the influence degree D_i, which represents the comprehensive influence value of the row factor on all other factors. The elements in matrix T are added as the affected degree R_i by column, indicating the comprehensive influence value of all other factors in that column. The formulas are as follows:

$$D_i = \sum_{j=1}^{n} t_{ij},\quad i = 1, 2, \ldots, n, \tag{6}$$

$$R_i = \sum_{i=1}^{n} t_{ij},\quad i = 1, 2, \ldots, n. \tag{7}$$

(2) Normalize the left value (ls) and right value (rs):

(3) Calculate the clear value after defuzzification:

(4) Calculate the average clear value:

The sum of the influence degree and affected degree is called centrality, which indicates the position of the factor in the system and the size of its role. The difference between the influence degree and the affected degree is called causality, which reflects the causal relationship between the influencing factors. If the causality is greater than 0, the factor has a great effect on other factors and is called the factor of cause. If the causality is less than 0, the factor is greatly affected by other factors and is called the factor of result. The formulas are as follows:

$$m_i = D_i + R_i, \quad i = 1, 2, \ldots, n, \tag{8}$$

$$\begin{aligned} n_i &= D_i - R_i, \quad i = 1, 2, \ldots, n, \\ H &= T_i - R_i, \quad i = 1, 2, \ldots, n. \end{aligned} \tag{9}$$

3.2. ISM. The ISM method is also needed to classify the system structure to transform the ambiguous ideas and views into an intuitive model with structural relationships. The direct influence matrix is calculated, and the comprehensive influence matrix is obtained. The comprehensive influence matrix t reflects only the mutual influence relationship and degree between different factors and does not consider the influence of factors on itself. Therefore, it is necessary to calculate the overall influence relationship reflecting system factors, i.e., the overall influence matrix. The calculation formula is as follows:

$$\begin{aligned} H &= T + E = h_{ij}, \\ \lambda &= \alpha + \beta, \end{aligned} \tag{10}$$

where α and β are the mean and standard deviation of all elements in the comprehensive influence matrix T, respectively.

A threshold is used to remove the redundant factors, and the reachable matrix is obtained:

$$\begin{aligned} M &= \left[m_{ij}\right]_{n*n}, \quad i = 1, 2, \ldots, n; j = 1, 2, \ldots, n, \\ m_{ij} &= \begin{cases} 1, & h \geq \lambda, \\ 0, & h \leq \lambda, \end{cases} \quad i = 1, 2, \ldots, n; j = 1, 2, \ldots, n. \end{aligned} \tag{11}$$

1 means there is a direct effect between the two factors, and 0 means there is no direct effect between the two factors.

The reachable set $L(f_i)$, antecedent set $P(f_i)$, and common set

$$C(f_i) = L(f_i) \cap P(f_i), \tag{12}$$

are obtained by hierarchical processing.

Finally, the ISM is determined by the reachable set and common set.

4. Results

In order to standardize the practice of intelligent transportation and ensure the embedding of blockchain technology, it is necessary to evaluate the rationality and standardization of the research through the expert committee. The expert committee is composed of 7 experts who have more than 8 years of experience in intelligent transportation enterprise or working in relevant departments. Prior to the process of evaluation, the committee need to prove that the attributes proposed in the study (including aspects and criteria) can reflect the real situation of the intelligent transportation industry. Once an expert disagrees with the proposed measures, the committee needs to discuss the arguments until all experts agree. Therefore, several rounds of discussion will be repeated to ensure the reliability of the research. Data collection adopts individual face-to-face interviews to improve consistency and prevent the judgment of other experts from being affected. Then, according to the CFCS method, the original data are processed, and finally, the direct impact matrix for the influencing factors of blockchain technology on intelligent transportation is determined, as shown in Table 3.

The direct impact matrix of blockchain technology in intelligent transportation is standardized to obtain the standardized direct impact matrix. Then, according to the formula $T = G\ (E - G) - 1$, MATLAB software is used to calculate the matrix, and the comprehensive impact matrix is obtained, as shown in Table 4.

According to formulas (6)–(9), the influence degree, affected degree, centrality, and causality are calculated as shown in Table 5, and a causal relationship diagram is shown in Figure 1.

According to the positive and negative causality, 15 risk factors are divided into a cause set and a result set. Table 5 shows that there are 7 causal factors, which should be taken into consideration when developing measures, including Internet-based traffic management (C7), transaction cost (C1), credit evaluation system (C13), congestion management (C8), reward and punishment system (C12), timeliness (C6), and reliability (C5). As shown in Tables 4 and 5 and Figure 1, the corresponding influence degrees of C5, C6, and C12 are 2.3341, 2.2583, and 2.1056, which are the three most influential values among all factors, indicating that these three factors have the greatest influence on other factors. There are 8 result factors, including parking management (C11), urban greening layout (C15), urban traffic pollution (C14), financial cost (C4), management cost (C2), infrastructure construction cost (C3), convenient travel (C10), and urban space optimization (C9). They have a weaker impact on intelligent transportation under the blockchain technology, but are more susceptible to changes caused by other factors. Therefore, in actual management, proper attention and control should be given to help improve management effectiveness.

The degree of centrality reflects the importance of various influencing factors in the sustainable development system of blockchain-based intelligent transportation. Sorted by the degree of centrality, the factors in descending order are reliability (C5), reward and punishment system (C12), timeliness (C6), congestion management (C8), credit evaluation system (C13), Internet-based traffic management (C7), infrastructure construction cost (C3), transaction cost (C1), convenient travel (C10), urban space optimization (C9), management cost (C2), urban traffic pollution (C14), urban greening layout (C15), financial cost (C4), and parking management (C11). The degree of causality is positive and negative, the action direction is opposite, and the impact characteristics on intelligent transportation are

Table 3: The direct influence matrix of blockchain technology on intelligent transportation.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0.0000	0.4302	0.4048	0.4048	0.1381	0.1508	0.0873	0.0111	0.2143	0.2524	0.2143	0.2143	0.1889	0.2016	0.2016
C2	0.1254	0.0000	0.2270	0.1381	0.1635	0.1000	0.1254	0.0111	0.1508	0.1762	0.1127	0.0111	0.1381	0.0111	0.0111
C3	0.1381	0.1254	0.0000	0.0238	0.1127	0.1762	0.1635	0.1762	0.1508	0.0111	0.1254	0.1127	0.1889	0.4302	0.4302
C4	0.1889	0.1508	0.1635	0.0000	0.1889	0.0111	0.0238	0.0111	0.0238	0.0111	0.1127	0.1762	0.1127	0.0111	0.0111
C5	0.4048	0.4302	0.1000	0.2778	0.0000	0.2651	0.4302	0.4302	0.3032	0.2524	0.2651	0.2524	0.4556	0.2524	0.1889
C6	0.4048	0.1889	0.1000	0.2397	0.2524	0.0000	0.4302	0.4556	0.2524	0.2651	0.4302	0.2397	0.4556	0.1762	0.2651
C7	0.1635	0.2524	0.4302	0.2524	0.2524	0.1254	0.0000	0.1635	0.0111	0.4048	0.2524	0.2778	0.2524	0.0365	0.0365
C8	0.1508	0.1381	0.4556	0.1635	0.1127	0.1635	0.4556	0.0000	0.4048	0.4048	0.1635	0.1000	0.2524	0.1635	0.2524
C9	0.1000	0.1762	0.1127	0.1762	0.0111	0.1000	0.1635	0.2397	0.0000	0.1000	0.4556	0.0111	0.0111	0.2524	0.4048
C10	0.1381	0.1254	0.1000	0.1508	0.1127	0.1889	0.1127	0.2524	0.1889	0.0000	0.0111	0.0238	0.0111	0.4556	0.4048
C11	0.1127	0.1381	0.1254	0.2397	0.0238	0.0111	0.0238	0.0238	0.2524	0.1127	0.0000	0.0111	0.0111	0.0111	0.0111
C12	0.2524	0.2524	0.1127	0.2524	0.2778	0.2778	0.4556	0.4556	0.1889	0.1889	0.1889	0.0000	0.4048	0.2397	0.2397
C13	0.1889	0.2651	0.4556	0.2270	0.1762	0.2016	0.1000	0.1635	0.0111	0.1889	0.1254	0.4556	0.0000	0.4302	0.2524
C14	0.0111	0.0111	0.1635	0.0111	0.0111	0.0111	0.1000	0.1127	0.1127	0.1127	0.1000	0.1254	0.2270	0.0000	0.0111
C15	0.0111	0.0111	0.1254	0.0111	0.0238	0.0111	0.0111	0.2524	0.1635	0.1127	0.1762	0.1000	0.0111	0.1000	0.0000

Table 4: The comprehensive impact matrix of blockchain technology on intelligent transportation.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0.0580	0.1568	0.1610	0.1475	0.0764	0.0763	0.0781	0.0653	0.1038	0.1118	0.1103	0.0965	0.1031	0.1135	0.1111
C2	0.0601	0.0392	0.0911	0.0650	0.0613	0.0472	0.0607	0.0376	0.0647	0.0717	0.0610	0.0315	0.0647	0.0429	0.0417
C3	0.0714	0.0744	0.0632	0.0502	0.0579	0.0711	0.0846	0.0914	0.0802	0.0530	0.0804	0.0667	0.0923	0.1471	0.1450
C4	0.0700	0.0673	0.0715	0.0329	0.0643	0.0250	0.0354	0.0321	0.0328	0.0306	0.0543	0.0642	0.0570	0.0349	0.0329
C5	0.1733	0.1932	0.1452	0.1570	0.0726	0.1249	0.1885	0.1873	0.1540	0.1546	0.1563	0.1357	0.1955	0.1563	0.1396
C6	0.1703	0.1386	0.1411	0.1467	0.1220	0.0667	0.1848	0.1906	0.1420	0.1544	0.1883	0.1308	0.1908	0.1374	0.1537
C7	0.0979	0.1246	0.1727	0.1201	0.1055	0.0774	0.0690	0.1043	0.0648	0.1522	0.1183	0.1152	0.1235	0.0857	0.0816
C8	0.0953	0.1019	0.1875	0.1037	0.0760	0.0866	0.1679	0.0771	0.1533	0.1595	0.1118	0.0806	0.1239	0.1202	0.1386
C9	0.0555	0.0769	0.0765	0.0779	0.0294	0.0465	0.0731	0.0920	0.0450	0.0640	0.1440	0.0327	0.0397	0.0955	0.1297
C10	0.0682	0.0697	0.0779	0.0736	0.0549	0.0706	0.0707	0.1041	0.0870	0.0486	0.0522	0.0416	0.0492	0.1485	0.1372
C11	0.0438	0.0532	0.0529	0.0746	0.0203	0.0166	0.0238	0.0246	0.0756	0.0435	0.0261	0.0176	0.0207	0.0260	0.0273
C12	0.1339	0.1450	0.1366	0.1411	0.1250	0.1218	0.1879	0.1872	0.1216	0.1333	0.1309	0.0773	0.1785	0.1442	0.1412
C13	0.1046	0.1278	0.1824	0.1149	0.0912	0.0951	0.0959	0.1117	0.0691	0.1091	0.0971	0.1576	0.0791	0.1734	0.1304
C14	0.0251	0.0286	0.0698	0.0273	0.0214	0.0223	0.0487	0.0526	0.0486	0.0509	0.0482	0.0506	0.0761	0.0350	0.0335
C15	0.0220	0.0244	0.0567	0.0244	0.0202	0.0190	0.0284	0.0810	0.0624	0.0493	0.0643	0.0382	0.0247	0.0497	0.0308

Table 5: Comprehensive impact matrix analysis.

Factor	Influence degree	Affected degree	Centrality	Causality
C1	1.5695	1.2495	2.8190	0.3200
C2	0.8404	1.4213	2.2617	−0.5809
C3	1.2291	1.6862	2.9153	−0.4571
C4	0.7050	1.3570	2.0620	−0.6520
C5	2.3341	0.9985	3.3325	1.3356
C6	2.2583	0.9671	3.2254	1.2913
C7	1.6127	1.3977	3.0104	0.2150
C8	1.7838	1.4391	3.2228	0.3447
C9	1.0784	1.3048	2.3832	−0.2264
C10	1.1540	1.3866	2.5406	−0.2325
C11	0.5467	1.4436	1.9903	−0.8968
C12	2.1056	1.1369	3.2425	0.9688
C13	1.7395	1.4188	3.1584	0.3207
C14	0.6389	1.5104	2.1493	−0.8715
C15	0.5956	1.4744	2.0700	−0.8789

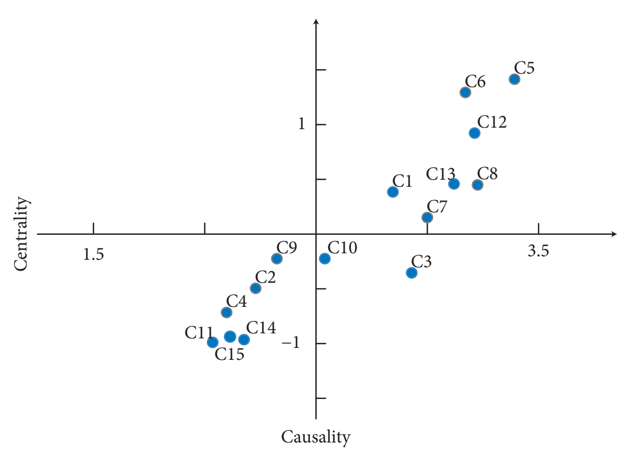

Figure 1: DEMATEL causal diagram.

also different. Figure 2 shows that factors according to the arrangement from big to small in turn are reliability (C5), timeliness (C6), reward and punishment system (C12), congestion management (C8), credit evaluation system (C13), transaction cost (C1), and Internet-based traffic management (C7). All these factors are active factors to promote intelligent transportation based on blockchain, which should be attached great importance.

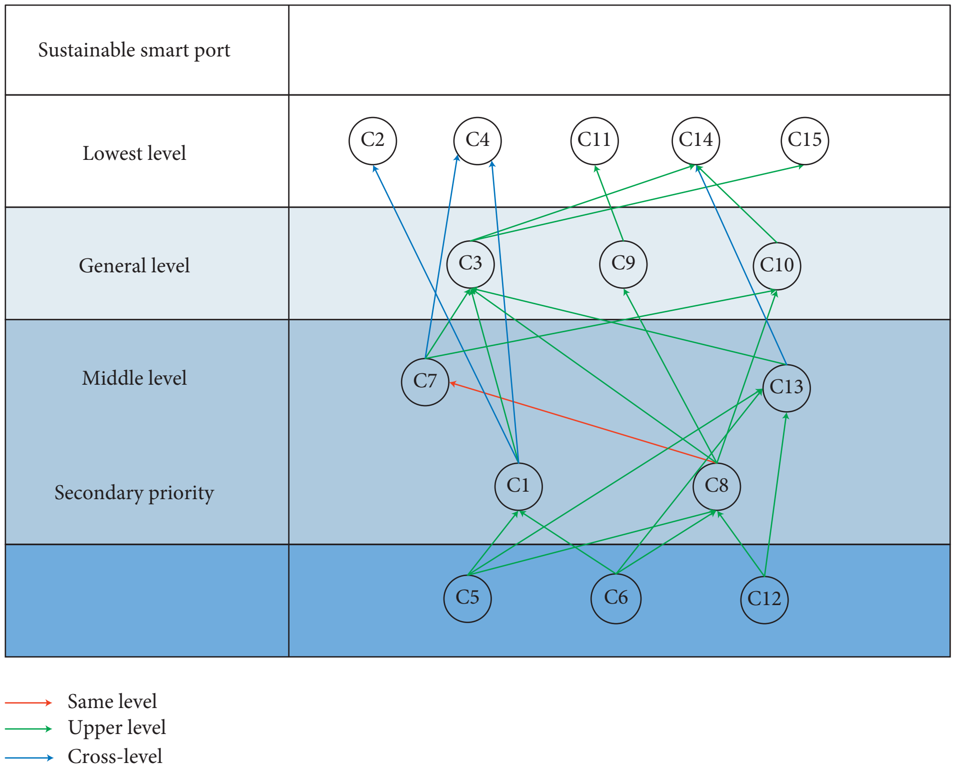

Figure 2: ISM structure model.

The overall influence matrix H obtained from formula (10) is shown in Table 6.

The reachable matrix M obtained from formula (11) is shown in Table 7.

The first-level decomposition structure is obtained from the reachable matrix and formula (12), as shown in Table 8.

Table 8 shows that the reachable set and common set intersect for factors C2, C4, C11, C14, and C15, so elements C2, C4, C11, C14, and C15 constitute the first-level influencing factors. The rows and columns of influencing factors C2, C4, C11, C14, and C15 in the matrix M are divided to obtain a higher-level decomposition matrix, and the above process is repeated. After multiple levels of division, the factor set Nq ($q = 1, 2, \ldots, 5$) of each layer is finally obtained as follows: first-level node $N1 = \{C2, C4, C11, C14, C15\}$; second-level node $N2 = \{C3, C9, C10\}$; third-level node $N3 = \{C7, C13\}$; fourth-level node $N4 = \{C1, C8\}$; and fifth-level node $N5 = \{C5, C6, C12\}$. The third-level node and the fourth-level node are merged, and the ISM model is established based on the above analysis, as shown in Figure 2.

According to the ISM analysis of the influencing factors, reliability (C5), timeliness (C6), and reward and punishment system (C12) compose the root of the influence of blockchain in intelligent transportation, and determining how to effectively track and control these factors is the key.

5. Discussions

This paper attempts to explore the sustainable development system of intelligent transportation based on blockchain technology. There are few studies on the application of blockchain technology in the field of intelligent transportation, and there is no comprehensive application system. This study systematically proposed a set of criteria about the development of intelligent transportation and constructed a hierarchical model.

In the index system, for the reward and punishment system, reliability and timeliness are at the first level and thus serve as the basis of the whole transportation consortium blockchain. The core of the entire blockchain-based intelligent transportation system lies in solving social problems, which depend on a complete top-level design. This paper proposes a top-level system design composed of a reward and punishment system and a credit evaluation system and rebuilds the social trust mechanism by encouraging users to participate in and conduct credit evaluations. The release of any information in the blockchain needs to be verified and can be traced by timestamp, ensuring the reliability of the information [42, 43], which is key to the stable operation of the system. Blockchain smart contract technology enables the free trade of access permits, allowing people to buy and sell as needed and adjust their travel strategies. Therefore, the improvement of social welfare brought about by solving and optimizing social problems highlights the characteristics of technology, which is consistent with the theory of social construction [44].

Transaction cost, congestion management, Internet-based traffic management, and the credit evaluation system are at the second level, which indicates that the development of blockchain-based intelligent transportation at the economic level mainly revolves around the intelligent contract

Table 6: Overall influence matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	1.0580	0.1568	0.1610	0.1475	0.0764	0.0763	0.0781	0.0653	0.1038	0.1118	0.1103	0.0965	0.1031	0.1135	0.1111
C2	0.0601	1.0392	0.0911	0.0650	0.0613	0.0472	0.0607	0.0376	0.0647	0.0717	0.0610	0.0315	0.0647	0.0429	0.0417
C3	0.0714	0.0744	1.0632	0.0502	0.0579	0.0711	0.0846	0.0914	0.0802	0.0530	0.0804	0.0667	0.0923	0.1471	0.1450
C4	0.0700	0.0673	0.0715	1.0329	0.0643	0.0250	0.0354	0.0321	0.0328	0.0306	0.0543	0.0642	0.0570	0.0349	0.0329
C5	0.1733	0.1932	0.1452	0.1570	1.0726	0.1249	0.1885	0.1873	0.1540	0.1546	0.1563	0.1357	0.1955	0.1563	0.1396
C6	0.1703	0.1386	0.1411	0.1467	0.1220	1.0667	0.1848	0.1906	0.1420	0.1544	0.1883	0.1308	0.1908	0.1374	0.1537
C7	0.0979	0.1246	0.1727	0.1201	0.1055	0.0774	1.0690	0.1043	0.0648	0.1522	0.1183	0.1152	0.1235	0.0857	0.0816
C8	0.0953	0.1019	0.1875	0.1037	0.0760	0.0866	0.1679	1.0771	0.1533	0.1595	0.1118	0.0806	0.1239	0.1202	0.1386
C9	0.0555	0.0769	0.0765	0.0779	0.0294	0.0465	0.0731	0.0920	1.0450	0.0640	0.1440	0.0327	0.0397	0.0955	0.1297
C10	0.0682	0.0697	0.0779	0.0736	0.0549	0.0706	0.0707	0.1041	0.0870	1.0486	0.0522	0.0416	0.0492	0.1485	0.1372
C11	0.0438	0.0532	0.0529	0.0746	0.0203	0.0166	0.0238	0.0246	0.0756	0.0435	1.0261	0.0176	0.0207	0.0260	0.0273
C12	0.1339	0.1450	0.1366	0.1411	0.1250	0.1218	0.1879	0.1872	0.1216	0.1333	0.1309	1.0773	0.1785	0.1442	0.1412
C13	0.1046	0.1278	0.1824	0.1149	0.0912	0.0951	0.0959	0.1117	0.0691	0.1091	0.0971	0.1576	1.0791	0.1734	0.1304
C14	0.0251	0.0286	0.0698	0.0273	0.0214	0.0223	0.0487	0.0526	0.0486	0.0509	0.0482	0.0506	0.0761	1.0350	0.0335
C15	0.0220	0.0244	0.0567	0.0244	0.0202	0.0190	0.0284	0.0810	0.0624	0.0493	0.0643	0.0382	0.0247	0.0497	1.0308

Table 7: Reachable matrix.

M	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
C2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C3	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
C4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
C5	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1
C6	1	1	1	1	0	1	1	1	1	1	1	0	1	0	1
C7	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0
C8	0	0	1	0	0	0	1	1	1	1	0	0	0	0	1
C9	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
C10	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
C11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
C12	0	1	0	1	0	0	1	1	0	0	0	1	1	1	1
C13	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0
C14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
C15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 8: First-level decomposition structure.

i	$L(f_i)$	$P(f_i)$	$C(f_i) = L(f_i) \cap P(f_i)$
C1: transaction cost	1, 2, 3, 4	1, 5, 6	1
C2: management cost	2	1, 2, 5, 6, 12	2
C3: infrastructure construction cost	3, 14, 15	1, 3, 5, 6, 7, 8, 13	3
C4: financial cost	4	1, 4, 5, 6, 12	4
C5: reliability	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 13, 14, 15	5	5
C6: timeliness	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 13, 15	6	6
C7: Internet-based traffic management	3, 7, 10	5, 6, 7, 8, 12	7
C8: congestion management	3, 7, 8, 9, 10, 15	5, 6, 8, 12	8
C9: urban space optimization	9, 11	5, 6, 8, 9	9
C10: convenient travel	10, 14	5, 6, 7, 8, 10	10
C11: parking management	11	5, 6, 9, 11	11
C12: reward and punishment system	2, 4, 7, 8, 12, 13, 14, 15	12, 13	12, 13
C13: credit evaluation system	3, 12, 13, 14	5, 6, 12, 13	12, 13
C14: urban traffic pollution	14	3, 5, 10, 12, 13, 14	14
C15: urban greening layout	15	3, 5, 6, 8, 12, 15	15

and is affected by the social level. The combination of economic benefits and social benefits is the core of sustainable development [45]. The use of smart contracts eliminates some unnecessary steps in the current trade settlement process [46]; blockchain technology can establish a consensus mechanism without the participation of intermediaries, which will improve the efficiency and scope of the market and make transactions closer to the direct point-to-point ideal state [47], all of which reduce transaction costs. Congestion is an urgent problem to be solved in the field of transportation. Eliminating congestion is related to the sustainable development of cities, can promote the optimization of urban structure, and is the basis for giving full play to the potential of cities [48]. In terms of management costs, immutable distributed accounting reduces the labor costs of governments and enterprises. All these results prove that institutional construction is the premise of economic development, and the stable operation of the market requires institutional constraints and incentives.

Infrastructure construction cost, convenient travel, and urban space optimization are at the third level, which continues to reflect the complex relationship between economic benefits and social benefits, and development at the social level is also affected by the economic level. The analysis and processing of traffic information and the optimization of route selection are inseparable from infrastructure construction. Improved infrastructure can provide more accurate and abundant traffic information, which can effectively manage traffic via the Internet, reduce traffic congestion, make travel more convenient, and improve users' travel experience. In addition, instead of considering travel optimization at the user level, we should adopt a comprehensive view of the influence of urban traffic to more reasonably divide the functions of the city and promote the sustainable transformation of cities [49, 50]. All these indicate that economic construction and social construction are inextricably linked.

The continuous improvement of environmental issues requires a solution to social problems [51]. Urban traffic pollution and urban greening layout are at the last level; they are influenced by social factors and are important features of the sustainable development of blockchain-based intelligent transportation. The impact of social problems on environmental problems is mainly reflected in traffic congestion. Automobile exhaust contains a large amount of CO, which is harmful to the human body. Emissions from diesel trucks and vehicle exhaust are mixed with a large amount of inhalable particulate matter, which is an important factor leading to disease [52, 53]. Reducing traffic congestion by limiting driving, planning the most fuel-efficient route, and controlling speed can effectively control the emission of traffic-related air pollutants, reduce greenhouse effects, acid rain, and other environmental problems, create a livable urban environment, and improve the quality of life of citizens [54]. In addition, the overall planning of urban construction and plant sites and the layout of urban greening according to local conditions can also purify the environment. Therefore, with the combination of blockchain technology and intelligent transportation, the solution of social problems will promote urban development in the direction of green environmental protection and sustainability.

In addition, one innovation of this paper is its study of the related issues in the field of blockchain-based intelligent transportation from the perspective of finance and taxation. The application of blockchain will make the transaction information more real and transparent to companies and the financial and tax administration department. In the past, it was difficult for the transportation industry to collect taxes, and the input was chaotic. Enterprise transport capacity is difficult to calculate, and the affiliation phenomenon has serious implications. The tax rate of Internet transportation companies is ambiguous [55, 56], and there are many loopholes in tax administration. Through the combination of blockchain technology and Internet of Things technology, transaction information can be automatically uploaded to the blockchain by an Internet of Things device, which can realize reliable records for every transaction and facilitate the supervision of the tax administration department. The stability of tax sources will promote tax reform and establish specific tax rates for Internet transportation enterprises, realizing the standardized management of the Internet transportation industry [57]. According to the research results of this paper, financial cost, parking management, management cost, urban traffic pollution, and urban greening layout are at the fourth level, which shows that there is still a long way to go in the use of blockchain technology to carry out fiscal and tax reform in the transportation industry.

To better understand the theoretical system of this paper, we further developed a blockchain-based intelligent transportation sustainable GCU application system based on stakeholder theory, elaborating how stakeholders in intelligent transportation combine with blockchain, as shown in Figure 3. Blockchain plays the role of a large transaction information database in this system. The information in the blockchain includes public and private information, and the blockchain uses asymmetric encryption technology to encrypt information [58, 59], providing a higher security factor for private information.

The model can be divided into three levels: the government layer, the company layer, and the user layer. First, traffic management departments in the government layer can issue traffic licenses through the blockchain, and individuals can trade freely according to their needs. In addition, traffic management departments can also release road condition information, collect data statistics, and conduct traffic supervision through the blockchain. Urban construction departments can integrate traffic information to carry out more reasonable urban planning. Second, for the transportation company layer, including passenger transportation companies and Internet-based transportation companies, the credit rating of operating drivers can be obtained through the blockchain, and real-time monitoring of operating vehicles can be realized through the combination of the blockchain and the Internet of Things. Information on every transaction of an enterprise will be accurately recorded in the blockchain through asymmetric encryption technology. Companies and accounting and auditing institutions can conduct accounting according to the transaction information in the blockchain. The financial and tax administration departments can check the accounts of companies under authorization to facilitate tax administration. Insurance institutions, as third-party enterprises,

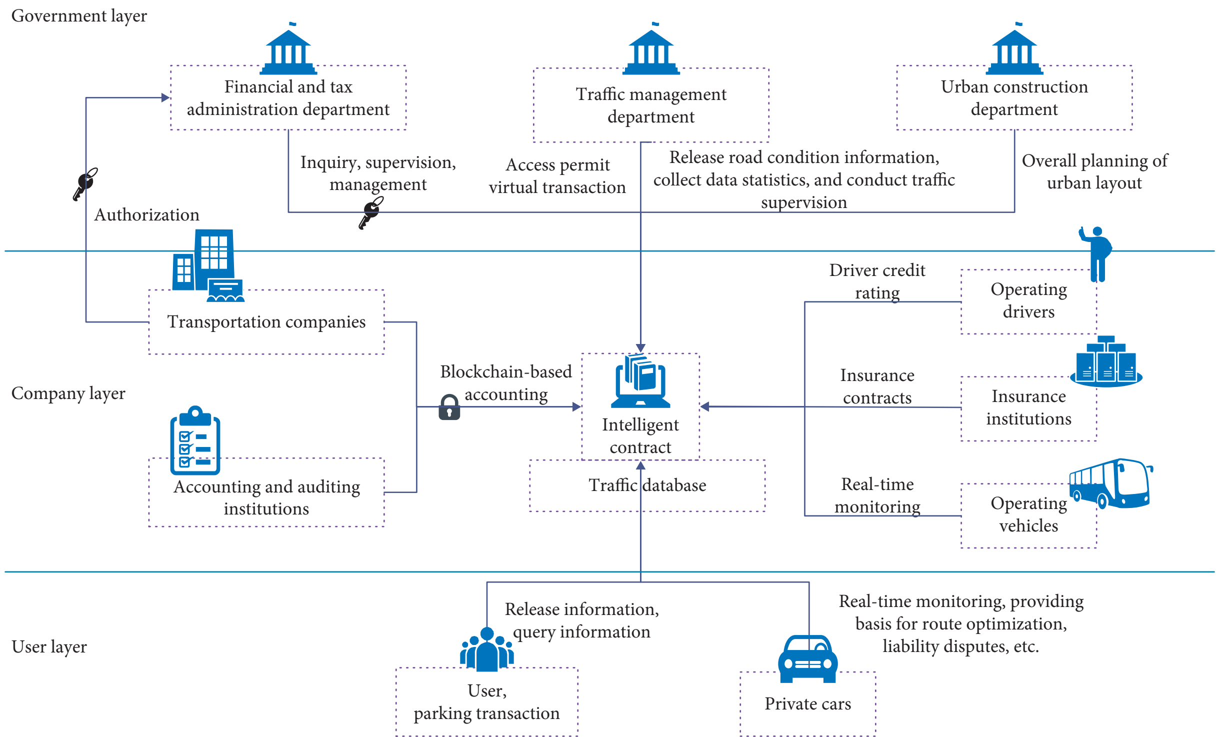

Figure 3: Blockchain-based intelligent transportation sustainable GCU application system.

can upload electronic insurance contracts and store them in the blockchain in the form of smart contracts [60, 61]. In the event of a traffic accident, the relevant authorization can be obtained to inquire about driving records and provide a basis for the settlement of accident disputes and insurance claims. Finally, at the user layer, the blockchain can be used to release or query traffic information, trade travel permits, or buy and sell parking that is not currently in use. Private cars can be monitored in real time through the combination of blockchain and Internet of Things devices, providing a basis for route optimization and liability disputes.

At this stage, the development of the blockchain is also facing some problems. For example, slower calculation speeds and large data volumes require more storage space, and low computing and storage capabilities of computer equipment may limit the use of blockchains [7, 62]. The basic blockchain processing that replicates all transaction history between all nodes is computationally expensive [63]. The immutability of the blockchain means that any modification to the smart contract, no matter how small, may be complicated in calculations, requiring the use of new blocks in the chain and increasing costs. Similarly, the combination of blockchain technology and intelligent transportation will also have corresponding problems. First, the blockchain uses public key encryption for transaction authentication and execution. Although this process is very secure, it requires the use of public and private keys. If one party loses or unwittingly publishes its private key, the system has no security mechanism to provide additional security. Secondly, the immutable append-only feature of the blockchain can ensure the integrity of the transaction, but may become an obstacle to use cases that require transaction changes [5]. Then, the principle that all nodes in the blockchain network store the complete transaction records of all information blocks can ensure network security credentials, but the addition of new blocks and subsequent transaction records is currently computationally expensive [22]. In addition, cultural, regulatory, legal, and logistical issues remain to be resolved to clear the way for further adoption of the technology [64]. Despite these uncertainties, the related research on the blockchain is still very hot, which will inevitably promote the development of related research on the blockchain.

6. Conclusions

At present, research on blockchain in the field of urban intelligent transportation is still in the exploratory stage. Most of the literature focuses on exploring the impact of the characteristics of blockchain on urban intelligent transportation. The development system for urban intelligent transportation under the blockchain is very vague. Few existing studies have explored the combination of blockchain and intelligent transportation from a sustainability perspective. Compared with previous studies, this paper considers the impact of blockchain technology on sustainable intelligent transportation development from the three aspects of the economy, society, and environment. The sustainable GCU application system of blockchain in intelligent transportation constructed in this paper is comprehensive and systematic. The comprehensive application of the fuzzy, DEMATEL, and ISM methods can not only screen out the unnecessary attributes, but also manage the complex interrelationships among the aspects and criteria.

However, there are still some limitations in this study. First, although the proposed criteria have been selected through the extensive literature review, it is still insufficient to cover all possible attributes. Second, the expert committee was consisted of the intelligent transportation management experts, and experts in other fields related to electronic technology, especially blockchain technology, should be included in the committee for increasing the scope and the applicable boundaries. Third, although the fuzzy set theory is used in this research to solve the problem of experts' subjective bias, there are still some errors that are difficult to eliminate completely that may have a certain impact on the research results. In addition, this study could also use other statistical tools, such as a structural equation model, to explore more influencing factors and carry out statistical verification of the model.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supplementary Materials

Expert questionnaire results. (*Supplementary Materials*)

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