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Monitoring Scheme for Safety Hazard Status of Urban Rail Transit Operation Equipment and Facilities Based on Blockchain Technology

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ABSTRACT

Urban rail transit plays a very important role in cities' social and economic development. To ensure the safe and stable operation of urban rail transit operation equipment and facilities, it is necessary to monitor a large number of safety hazard statuses and data and improve the over-centralisation of traditional monitoring. This paper designs a scheme for storing, validating and monitoring the safety hazard status of urban rail transit operation equipment and facilities based on blockchain technology. The safety hazards of equipment and facilities during the operation stage of urban rail transit are listed using the literature analysis method and the case study method. The European RAMS (reliability, availability, maintainability and safety) standard method is used to determine the safety hazard status of equipment and facilities by availability index. Based on the features of the consensus mechanism, smart contract and other features of blockchain technology, this paper designs an overall scheme for storing, verifying and monitoring the safety hazard status of equipment and facilities. This scheme provides a practical operation method for evaluating the safety hazard status of rail transit equipment and facilities, which is conducive to the safety rectification of the entire urban rail transit.

KEYWORDS

rail transit; equipment and facilities; safety hazard status; blockchain; status monitoring.

1. INTRODUCTION

Rail transit is a necessary part of urban traffic in China [1]. The 2021 Urban Rail Transit Statistical and Analysis Report pointed out that toward the end of 2021, 50 cities in the Chinese mainland were operating URT which had a total of 283 routes and 9,206.8 km length. The number of passengers carried by the URT system in the Chinese mainland was 23.69 billion in 2021 which was 34.7% higher than that in 2020. Since the total length of urban rail transit operation lines is growing, there are more and more operations accidents [2]. A statistical analysis of 1,230 cases of sudden accidents during the operation phase of the metro in six cities between 2014 and 2018 showed that accidents caused by equipment and facilities reached more than 85% [3]. Meanwhile, in the process of urban rail transit operation, the safety hazards of equipment and facilities such as door failure, line sinking and interval signal display failure seriously affect people's rail travel and life. Therefore, this paper focuses on the judgment and monitoring of the safety hazard status of the equipment and facilities factor in the operation stage. Data related to rail transit operations are currently dispersed across many cities because of reasons such as data safety, which makes it difficult to pull it all together. To realise data information sharing while ensuring data safety, an urgent problem must be addressed.

As an emerging technology, the rapid development of blockchain is breathtaking. In the early stage, blockchain technology was mainly applied in the field of digital cryptocurrency. With the embedding of asymmetric cryptographic algorithms, smart contracts and various consensus mechanisms, the application scenarios of blockchain technology have become more extensive. The characteristics of the blockchain system, such as decentralisation, traceability, safety and credibility, have led to disruptive changes and extensive applications in the Internet of Things, finance, medicine, cultural media, education, social governance, insurance and other fields.

A blockchain is essentially a distributed ledger technology (DTL) that is decentralised [4]. Blockchain technology organises and manages data blocks in a chronological manner similar to a chain table, which is suitable for storing data with sequential relationships that can be verified within the system, and uses encryption technology to encrypt data to ensure the integrity and safety of blockchain data [5]. Therefore, there are five benefits of using blockchain technology, as shown in *Table 1* below.

Table 1 – Benefits of using blockchain technology

Benefits for specific applications	Further description
Decentralisation	The decentralised system structure effectively improves data transmission efficiency, reduces time lag and broadens the technical application scenarios from the perspective of lower cost.
Openness	Besides the private information of the parties to the transaction being encrypted, the data of the blockchain are open to all, and the information of the entire blockchain is highly transparent.
De-trust	Blockchain adopts consensus-based specifications and protocols that enable all nodes in the entire system to exchange data freely and securely in a de-trusted environment.
Non-tamperability	The application of technologies such as hash functions in cryptography determines that the data of the blockchain cannot be tampered with, so the data stability of the blockchain is very high.
Traceability	The unique chain structure of the blockchain determines the traceability of the stored data, and every transaction data stored in the blockchain are traceable. The verified transaction information is time-stamped while being written to the block and adding a time dimension to the data.

With the development of the rail transit industry, it is very important to monitor the safety hazard status of equipment and facilities. Traditional condition monitoring methods such as intelligent transport system (ITS) information are not sufficient in real-time, and information data are difficult to share. Under the big data intelligent transport system, the speed of information data transfer and sharing is accelerated, but the private information data contained will be exposed to the risk of leakage. At present, the amount of data is increasing, and it is getting more and more complex. Safety storage of status monitoring data is an important element. Safety and privacy issues of traditional cloud storage technology are still a major concern. Its management is complex, requires a third party for unified management and is highly centralised.

This paper uses the advantages of blockchain technology such as decentralisation to solve the problem of monitoring the safety hazard status of equipment and facilities [6]. The characteristics of blockchain technology such as distributed storage, asymmetric encryption and consensus mechanism are used to conduct block-based encapsulation and distributed control of the real-time and historical data involved in different phases of storage, validation and monitoring of potential safety hazard status of equipment and facilities, thus finally realising the goal of efficient and safe monitoring of status data [7]. The main contribution of this paper is that it proposes for the first time a method to monitor the status of safety hazards in urban rail transit operation equipment and facilities using blockchain technology. It not only monitors the status data to protect data safety but also stores the status data in the blockchain to carry out safety rectification for the whole urban rail transit.

The remaining parts of this paper are organised as follows: Section 2 gives literature reviews. Section 3 lists the safety hazards of equipment and facilities. Section 4 introduces the monitoring scheme. Section 5 evaluates the safety hazard status of equipment and facilities. Section 6 presents the results and discussions. At the end of this paper, conclusions are drawn.

2. LITERATURE REVIEW

2.1 Monitoring of safety hazard status of urban rail transit operation equipment and facilities

The research on measuring and monitoring the operational availability of rail transit infrastructure has shown that the availability of rail transit infrastructure is closely related to training delay, so availability indicators could be used to measure and monitor the operation status and organisation parameters of urban rail transit infrastructure [8]. Hua et al. [9] designed an online monitoring and analysis system of urban rail transit vehicles to process and analyse the data that have been transmitted to the processing centre in real-time,

Table 2 – Safety hazards of equipment and facilities during the operation stage of urban rail transit

Target safety hazard	Primary safety hazards	Secondary safety hazards
Equipment and facilities	Vehicle system	Traction system
		Vehicle running gear
		Auxiliary power system
		Braking air source system
		Car body system
	Power supply system	Main substation
		Traction power supply system
		Power supply system for power lighting
		Power monitoring system
	Electromechanical system	Escalator elevator system
		Platform screen door and floodgate system
		Water supply and drainage system
		Ventilation and air conditioning system
		Fire protection system
		Environment and equipment monitoring system
		An automatic fare collection system
	Communication system	Transmission system
		Telephone system
		Closed circuit television monitoring system
		Broadcasting system
		Power supply and grounding system
		Clock system
		Passenger information system
		Communication optical cable line
		Wireless communication system
	Signal system	Interlocking system
		Automatic train protection system
		Automatic train monitoring system
		Automatic train operation system
	Line track system	Rail status
		Sleeper status
		Ballast bed status
		Turnout status
		Coupling part status
	Civil engineering system	Bridge system
		Roadbed and culvert system
		Car depot and comprehensive base system
	Maintenance system	Vehicle maintenance system
		Power supply maintenance system
		Electromechanical maintenance system
		Communication maintenance system
		Signal maintenance system
		Line track maintenance system
		Civil structure maintenance system

and to solve the problem of high-frequency real-time transmission of large amounts of data by analysing the operational status data and fault data. Song [10] designed an urban rail transit vehicle and equipment status monitoring system using real-time wireless detection of parameters, which can monitor equipment and vehicle status in real-time and realise the functions of wireless detection, transmission, display, storage and intelligent processing of information data. Wang et al. [11] proposed a safety intelligent monitoring and early warning system for urban rail transit facilities that can realise the collection, transmission and storage of monitoring data and intelligent early warning of the operation status of rail transit facilities. Based on the 2.5-dimensional perspective view to build a station monitoring model, it could display the operation status and fault information of key equipment in real-time, and could also determine the operation status of equipment [12]. However, these monitoring systems still have shortcomings, such as the status monitoring data cannot be shared with each node in time, a large amount of data being concentrated in the data management system, the problem of safety in the process of data transmission and other problems.

2.2 Application of blockchain in urban rail transit

Lin and Cao [13] proposed the application of blockchain technology in the settlement mode of the rail transit system, which improved the level of enterprise informatisation and contributed to the development of rail transit construction. The application of blockchain technology could promote intelligent rail transit and guarantee its operation safety, but the application of blockchain in rail transit was still in the initial stage [14]. Wen [15] combined the safety management of the metro project with blockchain technology to build a safety system based on blockchain technology and used the idea of game theory to demonstrate and analyse the transaction evaluation contract under this system. Blockchain technology can build a systematic safety protection mechanism for distributed rail transit edge computing networks [16]. The use of blockchain technology can effectively realise the process record of intelligent operation and maintenance, which can help realise the whole process tracking of operation and maintenance of urban rail transit system and improve the information safety of rail transit system. However, at present, the application of blockchain in urban rail transit is still in the initial stage, and there is a lack of independent and detailed research on each safety factor in each stage of the whole rail transit system.

2.3 Research summary

Although previous research has improved the performance of data sharing, the issue of restricting rail transit operations persists. There is a risk of data leakage in data transmission because there is no safety and reliable monitoring scheme. This paper proposes for the first time a method to monitor the status of safety hazards in urban rail transit operation equipment and facilities using blockchain technology. Data leaks and tampering can be prevented, centralised data management can be improved, and untimely data sharing can be avoided.

3. SAFETY HAZARDS OF EQUIPMENT AND FACILITIES

Urban rail transit is a complex dynamic system that involves multiple tasks [17]. Due to the complexity and unpredictability of rail transit, there are many safety hazards in the equipment and facilities during the operation of urban rail transit [18]. In this paper, the literature analysis method and case analysis method are comprehensively used, and the potential safety hazards of the equipment and facilities in the rail transit operation stage are listed by considering the factors of equipment and facilities, as shown in *Table 2*.

4. MONITORING SCHEME

4.1 Scheme model

The scheme is shown in *Figure 1*. The process of this scheme mainly includes:

Step 1. The safety hazard status of the equipment and facilities and the statistical and calculated data are stored in the uplink.

Step 2. The smart contract is used to initially verify the safety hazard status and data. A preliminary validation contract is set to verify the reliability and validity of the data.

Step 3. The validation results are stored on the chain while the validation information is stored in a distributed repository. Because the information data is huge and the storage of the blockchain is limited, a distributed repository is used to store some important but non-essential information on the chain [7].

Step 4. To prevent nodes from maliciously tampering with the information data, the distributed repository encrypts the stored information data. When data need to be accessed for data sharing, only the node with permission can access the repository [7].

Step 5. The monitoring institutions apply for access to the distributed repository. After the application is approved, the data in the repository are monitored and evaluated. Finally, the monitoring institutions upload and store the monitoring results on the chain.

Step 6. The Merkle root in the blockchain maintains the integrity and non-tampering of the verification data and can quickly locate the changed information data. The Hash value is a one-way encryption function that uniquely and precisely identifies a block. The timestamp is a time marker that records the time of block generation and plays the role of data verification. Random numbers establish communication channels to promote data consensus. Transaction information is responsible for recording the data in the blockchain [19].

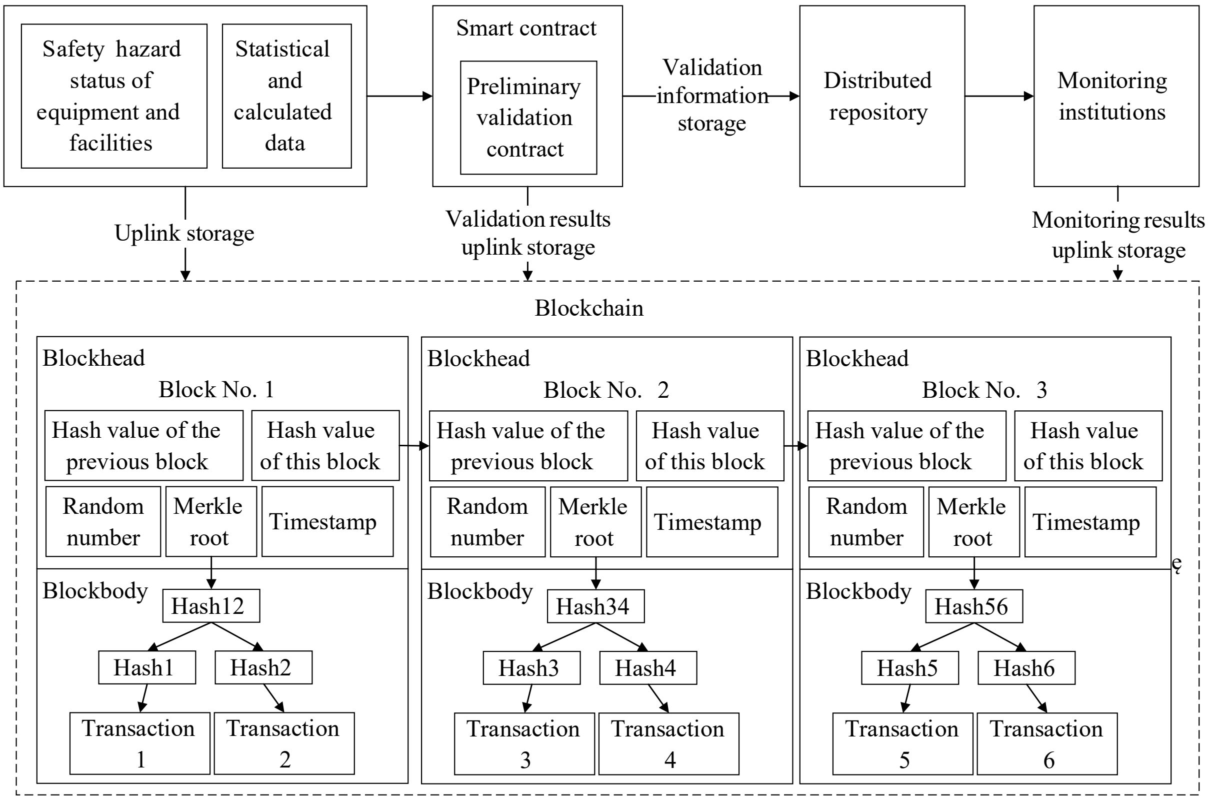

Figure 1 – Blockchain-based scheme model diagram

4.2 Blockchain consensus mechanism

Since there is no third-party management organisation, the consistency of nodes in the blockchain system must be guaranteed through the consensus mechanism. The consensus mechanism is one of the core technologies of blockchain, which is a mechanism set up to ensure that the data or information stored is true and consistent [20]. Any node in the blockchain network is not dependent on the central server and is highly decentralised.

Blockchain is divided into the public blockchain, private blockchain and consortium blockchain according to the degree of openness. The comparative analysis of three basic types is shown in *Table 3*. Anyone can read, trade and write on the public blockchain, which is a decentralised blockchain with open and transparent information. The private blockchain is controlled and managed by centralised management and its information is not accessible to the general public. It is a centralised structure. The consortium blockchain only opens all or part of its functions to members within the alliance and has the characteristics of partial decentralisation.

While combining the characteristics of urban rail transit, considering that the essence of blockchain technology is a decentralised distributed database and the service objects are all units or individuals participating in the rail transit operation, the consortium blockchain is more suitable for rail transit operation and management [15]. The consortium blockchain balances the decentralisation of the public blockchain and the high efficiency of the private blockchain.

Table 3 – Comparative analysis of the basic types of blockchain

Basic types of blockchain	Participants	Degree of centralisation	Bookkeeper	Outstanding features
Public blockchain	Anyone	Decentralisation	All participants	The high degree of decentralisation
Private blockchain	Within an individual or organisation	Centralisation	Customisation	Fast and low cost
Consortium blockchain	Alliance members	Polycentricity	Consortium members consult to determine	Efficiency and cost optimisation

The consensus mechanism is the core part of the blockchain system, which directly affects the efficiency, safety and stability of the blockchain system [21]. It is possible to ensure that blockchain nodes participating in a consensus process are valid by using the consensus mechanism of blockchain. The common consensus mechanisms of blockchain are shown in *Table 4*.

Table 4 – Comparative analysis of common consensus mechanisms in blockchain

Consensus mechanism	Type	Fault tolerance rate	Features
POW – proof of work	Public blockchain	50%	Simple algorithm and high operability
POS – proof of stake	Public blockchain	50%	Less resource consumption
DPOS – delegated proof of stake	Public blockchain	50%	Higher performance efficiency
PBFT – practical Byzantine fault tolerance	Consortium blockchain	33%	High safety and short transaction confirmation time

A distributed network can reach consensus even if some nodes are malicious with the PBFT. Therefore, this paper adopts PBFT as the consensus mechanism for rail transit operation based on blockchain technology. One of the most popular consensus algorithms in the blockchain is practical Byzantine fault tolerance (PBFT) [22]. This mechanism needs to solve the problem of how to ensure that other reliable nodes can reach a consensus under the premise that malicious nodes are known to exist. If the number of wrong nodes does not exceed 1/3, PBFT can guarantee the performance of the blockchain [23].

4.3 Preliminary validation of safety hazard status and data based on smart contract

In a smart contract, the terms of the contract are automatically executed. As long as it is put into use, it can automatically execute contract contents according to internal rules [24]. The blockchain-programmable smart contract provides technical support to achieve custom functions and expand application scenarios and handles various contract protocols by coding and designing different transaction processing and execution mechanisms [25]. Therefore, the smart contract can be used to preliminary validate the safety hazard status and data. The preliminary validation contract strictly reviews and verifies the reliability and validity of the safety hazard status and data. The preliminary validation contract of the rail transit project is shown in *Figure 2*.

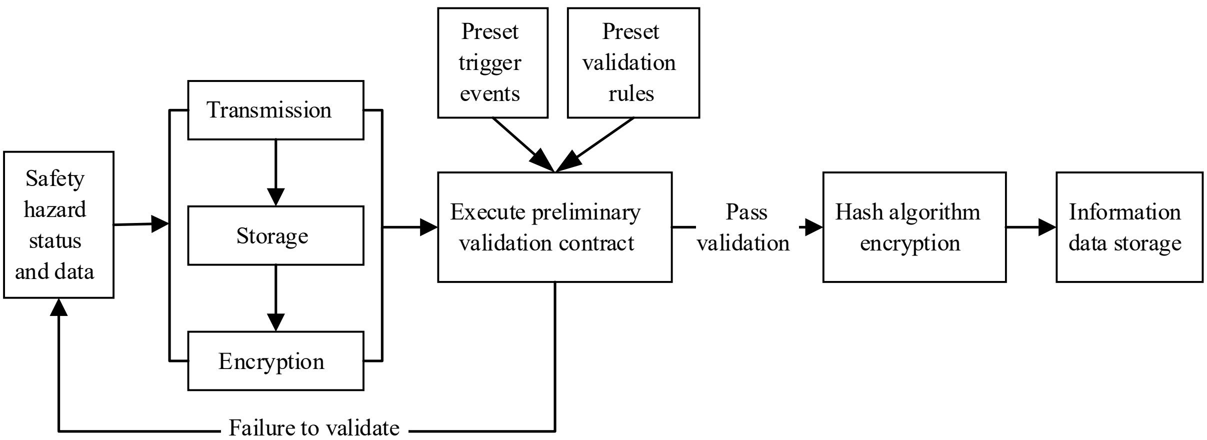

Figure 2 – Preliminary validation contract

The Hash algorithm encrypts the information data to prevent the information data from being tampered with [26]. After encryption, only nodes with access rights can access the information data, and nodes without access rights will be automatically rejected.

4.4 Safety hazard status monitoring and data analysis

The asymmetric encryption algorithm is a key secrecy method that requires two keys: a public key and a private key. The public key and private key can ensure the safety of information and transactions of each node. The public key is used for data encryption, and only the node with the corresponding information can use the corresponding private key to decrypt data. The private key ensures that information cannot be stolen or tampered with [27]. This algorithm greatly increases the difficulty of tampering with data and is a reliable basis for safety management.

In the process of safety hazard status monitoring and data analysis, only authorised nodes of the control centre can access the encrypted data. Then the data are obtained through public and private key verification and monitored and analysed to achieve safety and trusted data sharing [26].

In summary, the benefits of using blockchain technology for safety monitoring include the following:

– Intelligent monitoring: The data information is directly uploaded and stored in the chain, effectively reducing the cost and errors of manual monitoring, and making the data processing automatic and intelligent.
– Monitoring data cannot be tampered with: Once the data information is chained, it cannot be tampered with or falsified, enhancing the credibility of the data.
– Complete and traceable monitoring data: All on-chain data cannot be deleted and will be stored permanently to ensure the integrity and trustworthiness of on-chain data.
– Distributed storage: The monitoring data shall be stored and backed up in a distributed manner. When the data are damaged or deleted, they can be restored automatically to ensure data safety.

5. EVALUATION OF EQUIPMENT AND FACILITIES SAFETY HAZARD STATUS

Determining and evaluating the status of safety hazards is the foundation and the primary task to realise the blockchain technology-based monitoring scheme for the safety hazard status of urban rail transit operation equipment and facilities.

Since the 1980s, RAMS is introduced in the rail transit industry [28]. So far, RAMS engineering in the rail transit industry in developed countries has developed to a relatively advanced level. A systematic RAMS industry standard has been established, and a complete and efficient working system has been formed. It has a complete set of RAMS engineering technologies support, such as advanced design and analysis techniques and effective verification methods [29]. Europe has not only enabled the systematic development of RAMS engineering, but has also led to significant improvements in the reliability, maintainability, availability and safety indicators of rail transit [29]. In the domestic rail transit industry, however, it is still an emerging concept. At present, domestic rail transit is relatively weak in RAMS work, which is far from meeting the development needs of rail transit. There is a lack of industrial RAMS standards and guidance documents, RAMS professionals, systematic RAMS engineering systems and industrial RAMS information database. For the achievement of the safety, efficiency and economic goals of the project, it is necessary to discuss the problems of RAMS management to promote standardisation and globalisation of the urban rail transit industry [28].

According to the European RAMS standard, this study evaluates the safety hazard status of equipment and facilities in four aspects: reliability, availability, maintainability and safety. The evaluation of the safety hazard status of equipment and facilities evaluates both whether a piece of certain equipment or facility can properly perform its functions and whether the performance indicators of the equipment or facility are good [2].

It is assumed that there are only two states of "normal" and "fault" in the equipment and facilities. Reliability is the ability to be in the normal state; availability is the proportion of the normal state in the whole life cycle; maintainability is the ability to return to the normal state [30]. The term "capacity" is a broad concept, and the RAM indicator is quantified by using the "duration", i.e. "duration" is "capacity". Then the operation status time of equipment and facilities is shown in *Figure 3* below [31].

Figure 3, T_{tfi} is the duration of equipment and facilities under normal conditions; T_{tri} is the duration of equipment and facilities in fault state; T_{bfi} is the duration of the service cycle of equipment and facilities; n is the number of faults, n=1, 2, ..., n. The metrics for measuring RAM are obtained as follows.

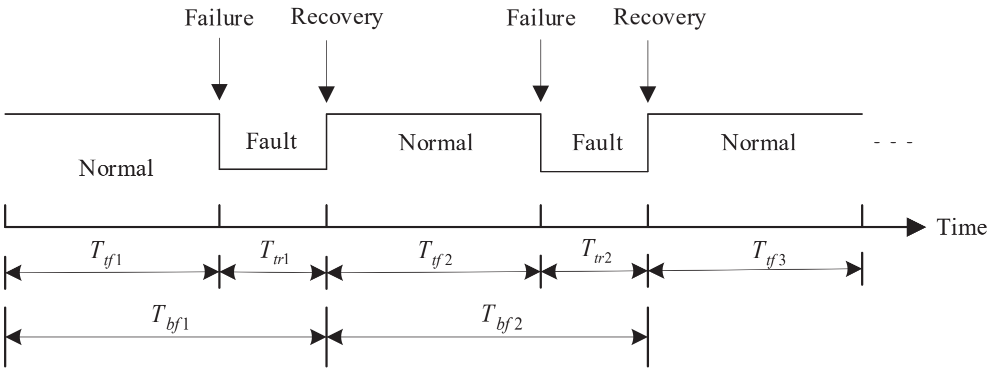

Figure 3 – Equipment and facility reliability, availability and maintainability operating status time diagram

5.1 Reliability indicators

Reliability is the ability to perform a specified function under specified conditions and within a specified time [32]. The probabilistic measure of reliability is also called reliability. We assess system equipment reliability in terms of mean time to failure (*MTTF*), which reflects the ability of the equipment to be in a normal state [33], see *Equation 1*.

$$MTTF = \frac{T_{tf1} + T_{tf2} + \cdots + T_{tfn}}{n} \tag{1}$$

5.2 Availability indicators

Availability is the degree to which a task is in a working or usable state when it is needed and started at any random moment [30]. The probability measure of availability is also called usability. The ratio of *MTTF* to mean time between failures (*MTBF*) *A* (i.e. the proportion of equipment and facilities in normal condition over their entire life cycle) is used to assess equipment and facility availability [33], see *Equation 2 and 3.*

$$MTBF = \frac{T_{bf1} + T_{bf2} + \cdots + T_{bfn}}{n} \tag{2}$$

$$A = \frac{MTTF}{MTBF} \cdot 100\% \tag{3}$$

5.3 Maintainability indicators

Maintainability is the ability to be maintained or restored to a specified state under specified conditions and for a specified time when repaired according to specified procedures and methods [34]. The probability measure of maintainability is also called the maintenance degree. We evaluate maintainability in terms of mean time to restore (*MTTR*), which reflects the ability of equipment and facilities to return to normal conditions [2], see *Equation 4*.

$$MTTR = \frac{T_{tr1} + T_{tr2} + \cdots + T_{trn}}{n} \tag{4}$$

5.4 Safety indicators

Safety refers to the characteristic of avoiding unacceptable risks, that is, the ability not to cause injury or death to people, harm to physical health and the environment, and not to cause damage or injury to equipment and property. The purpose of the safety study is to ensure the personal safety of passengers and the safe operation of rail transit. Safety is the analysis of the hazards of equipment and facilities to seek the lowest accident rate and thus counteract the risk of damage. The improvement of the safety performance of the equipment and facilities is the current need for the development of rail transit. The competition in the urban transport industry is very fierce. To meet the market demand, it is necessary to meet the standards of safety, speed, comfort, efficiency and low energy.

Safety refers to the ability of equipment and facilities to be in a normal state and a safety failure state [35]. For safety, the failure status of equipment and facilities can be divided into safety failure state and hazardous failure status. We use "duration" to quantify the S indicator. *Figure 4* shows the timing diagram of the safety operation status of the equipment and facilities [31].

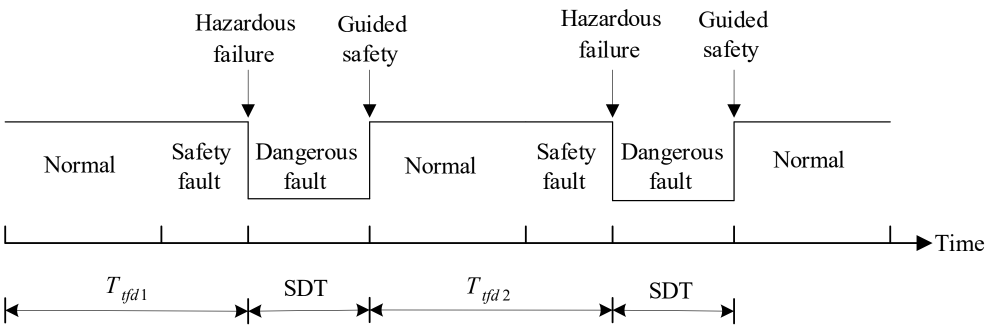

Figure 4 – Equipment and facility safety operation status time diagram

In *Figure 4*, T_{tfdi} is the duration when the equipment and facilities are in a relatively safe state; SDT is the duration when the equipment and facilities are dangerously faulty and not repairable. The metrics for measuring S are obtained as follows; by using the mean time to fail dangerous (*MTTFD*) as a safety measure, see *Equation 5*.

$$MTTFD = \frac{T_{tfd1} + T_{tfd2} + \cdots + T_{tfdn}}{n} \tag{5}$$

The above analysis reveals that reliability, availability, maintainability and safety evaluate the operation status of equipment from different perspectives respectively, and their essence is the same. Therefore, choosing "availability" to evaluate the safety hazard status of equipment and facilities can more intuitively grasp the safety operation status [2]. It is classified into 4 classes according to the calculation results, as shown in *Table 5*. At the same time, reliability, maintainability and safety are used as auxiliary judgments of the safety hazard status, to comprehensively grasp the operation status of system equipment [2].

Table 5 – Safety hazard status level and description of equipment and facilities

Safety hazard status level	Grade evaluation	Grade description
1	Healthy	Availability values of 0.9~1.0
2	Good	Availability values of 0.8~0.9
3	Dangerous	Availability values of 0.6~0.8
4	Serious	Availability values of 0~0.6

6. RESULTS AND DISCUSSIONS

6.1 Implementation of RAMS method

Wuhan Metro Line 5 is the first fully automated metro line in Wuhan, Hubei Province, which has achieved the highest level of automatic operation in the world today. The total length of Metro Line 5 is 35.1 km, with 25 stations. Relying on the Wuhan Metro Line 5 project, the automatic train monitoring system equipment of the signalling system is used as an example, and the data of metro operation failure and maintenance records from January to July 2022 are counted to determine the safety hazard status of the automatic train monitoring system equipment of Wuhan Metro Line 5.

We take the automatic train monitoring system equipment of the signalling system as an example, and the equipment failure maintenance data from January to July 2022 were counted. The reliability, availability, maintainability and safety indexes are calculated respectively, and the safety hazard status is judged. The results are shown in *Table 6*.

As can be seen from *Table 6*, the safety hazard status of the automatic train monitoring system equipment of Wuhan Metro Line 5 from January to July is healthy, indicating that its safety hazard level is low.

Table 6 – Safety hazard status of automatic train monitoring system equipment

Date	Number of failures	Total failure time [min]	*MTTF* [h]	*MTBF* [h]	*MTTR* [h]	*MTTFD* [h]	*MTTF/MTBF*	Safety hazard status
January	2	550	360.19	370.08	4.59	361.64	0.9733	Healthy
February	3	780	216.73	222.78	4.33	217.68	0.9728	Healthy
March	6	2114	119.84	121.72	5.87	119.95	0.9846	Healthy
April	5	1350	140.71	142.46	4.50	141.06	0.9877	Healthy
May	2	420	354.90	370.69	3.5	355.26	0.9574	Healthy
June	10	2854	70.27	70.52	4.76	71.28	0.9965	Healthy
July	7	2260	99.07	104.55	5.38	100.19	0.9476	Healthy

However, in terms of reliability and maintainability data, in January and May, the automatic train monitoring system had the lowest number of equipment failures, a longer average safe operating time per failure, and a relatively short average duration of each failure, indicating that the severity of system equipment failures was low. In June, the number of failures was the highest and the average safe operating time was the shortest, but the average duration of each failure was relatively low, indicating that although the failure frequency of the automatic train monitoring system equipment was the highest, the severity was low. Therefore, the frequency of maintenance should be increased to improve maintenance efficiency. Although the number of failures in March was less than that in June, the average duration of each failure was the longest, indicating that the severity of the failures was higher. It is necessary to strengthen the maintenance and rectification of system equipment to ensure the normal and safe operation of the system equipment.

From the safety data, the safety in January and May was relatively high, while the safety in June was very low. Therefore, measures should be taken to supervise and renovate the system equipment.

Through the verification of Wuhan Metro Line 5, the results are consistent with the actual situation. This shows that the results obtained by using the RAMS standard method to determine the safety hazard status of equipment can provide rationalised suggestions for the safety improvement of equipment of rail transit.

The determination of the safety hazard status of equipment and facilities is an indispensable part of the rail transit operation stage. The merits of the RAMS standard method for determining the safety hazard status of equipment and facilities are summarised as follows:

- The RAMS standard method is closely related to the whole rail transit system and can effectively solve the problems related to rail transit.
- Based on the RAMS standard method, a series of problems that arise from the wide range of failure mode categories in rail transit systems can be solved.
- The RAMS standard method is adopted in this paper to quantify the level of availability, reliability, maintainability and safety, and to obtain the ability to prevent and continuously improve the occurrence and development of equipment and facilities failures and accidents.
- At present, the biggest gap between China's rail transit and foreign developed countries lies in RAMS. There is no or little consideration of RAMS research and application in China. According to the current situation of urban rail transit in China, the research and application of the RAMS method must be carried out to raise the development of urban rail transit in China to a new level.

6.2 Implementation of blockchain

The crowd-share blockchain monitoring platform (V1.0) is dedicated to building a visualised operation, maintenance and monitoring platform. It can monitor the data on the chain in real-time with automatic monitoring and adaptation mechanisms. The crowd-share blockchain monitoring platform has the characteristics of intuitive visualisation and efficient compatibility. It can monitor the data on the chain visually and monitor the state of safety hazards more intuitively and supports the rapid deployment and construction of blockchain monitoring platforms and various frameworks.

The crowd-share blockchain monitoring platform first stores the device safety hazard status and related raw data, calculation data and results on the blockchain obtained by calculation in Section 6.1. Then it verifies the reliability and validity of the safety hazard status and data by setting up a preliminary validation contract, stores the verification results on the blockchain, and stores the verification information in the distributed repository. The distributed repository encrypts all the information data in the repository, monitors and evaluates the data in the repository by applying for access, and stores the monitoring results on the chain. The basic architecture of the crowd-share blockchain monitoring platform is shown in *Figure 5*.

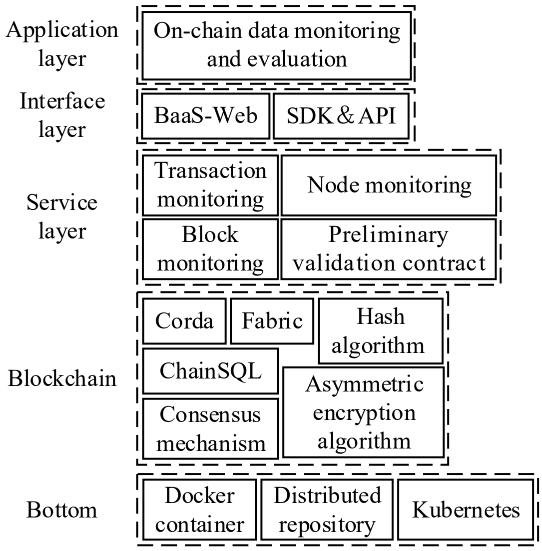

Figure 5 – Crowd-share blockchain monitoring platform basic architecture

The monitoring of equipment and facility safety hazards is an essential part of urban rail transit operations. Compared with traditional methods, the advantages of automated safety hazard status monitoring are summarised as follows:

– Blockchain-based safety hazard status monitoring process is automated, which saves a lot of human resources, material resources, financial resources and time.
– The integrity and safety of data information on the blockchain are guaranteed by using the characteristics of blockchain's non-tamperability and traceability; the decentralised and multi-party collaboration characteristics of blockchain are used to make data information securely shared and to achieve multi-party collaborative processing to guarantee the implementation and effective work.
– The solution can also be widely used in the construction phase of urban rail transit as well as in construction and other fields.

7. CONCLUSIONS

This paper lists the safety hazards of equipment and facilities in urban rail transit operations through literature analysis and other methods because of the frequent occurrence of accidents caused by equipment and facilities and the safety hazard status directly affecting the safety of operation. At the same time, the European RAMS standard method is used to determine the safety hazard status of equipment and facilities. Finally, based on blockchain technology, this paper designs an overall scheme for storing, verifying and monitoring the safety hazard status of equipment and facilities. The advantages of blockchain technology are used to make the data traceable, unalterable and transparent. The distributed storage, Hash algorithm cryptography, asymmetric encryption algorithm, consensus mechanism, smart contract and other features of blockchain technology are used to establish a monitoring scheme model, which leads to efficient and safe monitoring of status data.

Through the study of blockchain applications for monitoring the safety hazard status of equipment and facilities, the following conclusions are obtained:

1) This paper innovatively applies blockchain technology to the monitoring of safety hazard status. The characteristics of decentralisation, safety and anonymity of blockchain technology are used to solve the prob-

lems of malicious tampering and untimely sharing of data, which provides data support for the investigation of safety hazards and has important reference significance for the research of monitoring the safety hazard status in the field of rail transit.

2) The distributed data storage based on blockchain technology can realise the integrated management mode of safety hazard status monitoring. When there are safety hazards in equipment and facilities, the monitoring organisation can trace the status data to analyse the causes of safety hazards and make corresponding rectifications for rail transit.
3) This study can also be widely used in many aspects such as the construction stage of rail transit and other safety hazard factors in addition to equipment and facilities, which has important research value and a wide range of application scenarios.
4) However, this study also has some limitations. First of all, smart contract technology still has certain safety problems, such as re-entry vulnerabilities and other safety issues, which present new technical challenges for developers and leaves more room for progress in smart contracts. Secondly, there is a lack of skilled blockchain technology operators and a strong regulatory framework because blockchain technology is more complex and only a small number of people can fully master its application. Thirdly, the implementation of blockchain technology applications requires massive infrastructure upgrading and significant energy consumption. Last but not least, blockchain technology has limited scalability and storage problems. Currently, blockchain technology is still developing and these limitations will be improved and solved.
5) The application of blockchain technology in the field of urban rail transit is still in its initial stage, and further research can be conducted in the following aspects: a. the application of blockchain technology in urban rail transit materials; b. the application of blockchain technology in intelligent scheduling; c. the application of blockchain technology in urban rail transit communication networks; d. the application of blockchain technology in urban rail transit automatic ticketing.

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基于区块链技术的城市轨道交通运营设备及设施安全隐患状态监测方案

摘要

城市轨道交通在城市的社会和经济发展中起着非常重要的作用。为保证城市轨道交通运营设备及设施的安全稳定运行，需要对大量的安全隐患状态及数据进行监测并

改进传统监测的过中心化。本文设计了基于区块链技术的城市轨道交通运营设备及设施安全隐患状态的存储、验证、监测为一体的方案。采用文献分析法和案例分析法列出了轨道交通运营阶段设备及设施存在的安全隐患。采用欧洲RAMS标准法，以可用性指标判断设备及设施的安全隐患状态。本文基于区块链技术的共识机制和智能合约等特点，设计了设备及设施安全隐患状态存储、验证和监测整体方案。该方案为轨道交通设备及设施安全隐患状态评价提供了一种切实可行的操作方法，有利于对整个城市轨道交通进行安全整改。

关键词：
轨道交通；设备及设施；安全隐患状态；区块链；状态监测