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Blockchain-Based Emergency Information Sharing System for Public Health Security

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Abstract: The coronavirus disease 2019 (COVID-19) pandemic has caused severe human casualties and economic loss. Bolstering research on the coordination of public health security and emergency information is imperative. As such, building a more efficient and credible emergency information-sharing system has become a core strategy in optimizing public health security information management in China. This study analyzes the structure and implications of public health security emergency information and proposes a new structure for emergency information management during epidemic outbreaks in China. We created a hierarchical blockchain model based on the blockchain distributed trust mechanism for information sharing among emergency response departments. We elaborated on the emergency information consortium blockchain, block structure, and implementation of the sidechain interaction mechanism. The upload, sharing, download, and backtracking processes for emergency information were presented. Using the COVID-19 epidemic control in Nanjing as an example, we verified the validity of this model through scenario simulations and proposed epidemic-response policy recommendations. This study aimed to provide a decision-making reference and feasible path for building a new public health information system in China that meets the prevention and control needs during major epidemics.
Keywords: COVID-19 pandemic; public health security; emergency information; sharing; consortium blockchain

1 Introduction

In 2020, the global outbreak of the novel coronavirus disease 2019 (COVID-19) caused severe human casualties and economic turmoil, quickly becoming an international public health security crisis. COVID-19 public health incidents are characterized by multiple sources, rapid spread, differentiated distribution, and unpredictable hazards [1]. Furthermore, this manner of crisis typically lacks timely communication and verification, leading to inefficient coordination between government departments. Consequently, it becomes difficult to secure supplies, ensure timely response, and identify clear lines of responsibility. Unfortunately, no mature emergency information coordination mechanism has been developed [2]. It is crucial to reinforce existing research on public health security systems and emergency information-sharing mechanisms. A valid and effective emergency information-sharing model needs to be developed to support China's public health security, and emergency information management. [3,4].

Research on emergency information management began in the 1960s, with the aim of improving emergency information management by applying information technology [4]. Local governments in the United States deal with various emergencies through the National Emergency Management System (NIMS) [5], enhancing emergency

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management capabilities through information technology. In 2008, the Canadian office of Public Safety and Emergency Preparedness formulated a framework to improve urban emergency management [6]. The frequency of public health and safety emergencies has increased dramatically in the 21st century, especially with major infectious disease outbreaks such as severe acute respiratory syndrome (SARS), influenza A, Ebola, and COVID-19. Ali analyzed the influence of globalization on the spread of the SARS virus and its prevention and control. They emphasized the impact of major infectious disease outbreaks on politics, the economy, and society [7]. Marcus et al. reported that the SARS outbreak significantly inhibited GDP and domestic investment [8]. Such crises have put tremendous strain on the development of public health, the economy, and society.

Consequently, the academic community has begun focusing on research topics related to public health security. They have focused particularly on building cross-regional and inter-departmental emergency response mechanisms and a safer, more efficient public health emergency information sharing system [9]. Errors and delays in emergency decision-making for public health crises are typically caused by information asymmetry. It follows that collaborative sharing of emergency information plays an essential role in incident response and handling [10–13]. Information is becoming crucial in the management and control of epidemics. Intelligent control of public health security events can be realized by managing the three stages of emergency outbreak information. Emergency information is critical for rapid emergency response and decision-making [14]. Moreover, research indicates that emergency information collection, processing, and transmission encompasses over 50% of emergency control [15]. Therefore, emergency information sharing plays a vital role in managing public health security incidents. It is difficult to respond to complex and changeable public health incidents because of the fragmentation, procedural, and timing constraints involved in building a more efficient, safe, and credible emergency information sharing and cooperation mechanism [16,17].

The current core requirements of China's public health, emergency, and information management systems are that they should be safe, efficient, and provide real-time information sharing [18]. The application and popularization of big data technology provide new ideas for disaster emergency management [19]. The ability to collaborate and share emergency information can ultimately be improved through digital and intelligent technology. Blockchain has basic features such as decentralization, smart contracts, information sharing, and peer-to-peer transmission, synergizing well with emergency information management [20]. Its consensus mechanism can construct a safe and reliable information-sharing channel and ensure the authenticity of information with its tamper-proof feature [21]. In addition, cross-chain technology in the blockchain can make public health safety management hierarchical and resilient. By constructing consortium blockchains, the sharing obstacles and missing data between organizations can be solved [22]. Data sharing and exchange can be realized.

Establishing a cross-organizational intelligence-sharing system can overcome communication and efficiency challenges. A key goal of emergency information research is to construct an information management system based on emergency information management and to improve the coordination and sharing mechanism of emergency information. There is currently a lack of systematic research on the content, boundaries, and hazard ratings of information regarding epidemics under normal and emergency situations. The existing public health emergency system has not adapted to high-speed circulation and rapid response requirements. Nor has it adapted to multiple simultaneous emergencies to prevent and control major epidemics. The construction of a public health safety emergency information system adopts a hierarchical management form. Blockchain, a cross-domain information-sharing technology, can be used to remove barriers between different levels. It can help establish a cross-subject integrated information-sharing mechanism and improve emergency intelligence management capabilities. Existing systems face the challenge of effectively handling the problems of information authenticity and redundancy. Inefficient cross-departmental and cross-regional collaboration under complex conditions poses another challenge.

This study first analyzed the structure, characteristics, problems, and organization and management model of China's public health security emergency information during the COVID-19 pandemic. A layered model for emergency information sharing based on consortium blockchains was proposed. Layered sidechain technology was used to solve the issue of excessive primary-chain information storage of the consortium blockchain. The tamper-proof blockchain feature was utilized to achieve information traceability and incident accountability while reducing consortium blockchain data redundancy and ensuring shared information and data security. It also improved the resilience of the public health security management system. Finally, this study established an emergency information sharing process, utilizing the epidemic situation in Nanjing as an example. The effectiveness of this model was verified through scenario simulation. In addition, countermeasures and suggestions for responding to the epidemic were proposed to provide a decision-making model for China's public health, security, and emergency information-

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sharing systems.

2 The structure and characteristics of China's public health security emergency information

2.1 The current management model of China's public health security emergency information

Currently, the organizational structure of China's public health security emergency information is flat and divided into five levels: country, province, city, county, and township. Public health security emergency management presents a top-down, vertical tree structure. Information transmission is typically limited to one department. Horizontally, coordination between departments is difficult and not conducive to the early warning and coordination needs of public health security incidents. From the perspective of the information transmission process, it mainly presents a vertical and unidirectional information transmission mode from county (district) level institutions to municipal, provincial, and national institutions. The public health emergency information-sharing system is a complex project involving multiple departments. Still, information is often transmitted only within the same department. Emergency information transmission takes time, and there is a single transmission channel. Information exchange between institutions in different regions and departments is lacking. It becomes difficult to ensure the real-time consistency of emergency intelligence, and the phenomenon of information islands is a serious issue. Poor emergency information communication is the leading cause of errors or barriers to decision-making. When a public health security incident occurs, it is often challenging to enable information exchange among various departments. This may exacerbate the scope of the incident. In addition, public health security incidents require multi-level manual approval from occurrence to reporting. The completeness and accuracy of the reported data are of paramount importance, and human factors greatly influence the information approval. Information reported to superiors for approval is also not transparent. Information sharing at horizontal levels in response to public health emergencies is lacking, and current protocols are insufficient.

It is difficult for China's vertical tree-like emergency response model to respond rapidly to public health emergencies, Simultaneously sharing emergency information between different departments becomes a challenge as a result. It is necessary to modify the traditional public health emergency information transmission mode. This entails building a more efficient, safe, and credible emergency information-sharing system, realizing cross-departmental and cross-level emergency information collaboration, and eliminating information barriers between departments.

2.2 Public health security emergency information structure under COVID-19

Public health security incidents are unpredictable due to the highly contagious nature of COVID-19, and it is difficult to fully judge its impact due to the multiple pandemic waves. It is also difficult to ensure the authenticity and security of emergency information. Concurrently, this information is a multi-domain and multi-departmental collection of related information. It includes five primary information sources: epidemic, medical, government, public opinion, and media. The development of the epidemic is at the core of this public health emergency, and the infection and spread of COVID-19 are essential variables. In response to the epidemic's development, the clinical treatment (in medical institutions) and public health intervention (from disease control institutions) are two important measures to effectively alleviate the spread of the epidemic in a timely and effective manner. In the face of this public health emergency, the government is at the core of the epidemic crisis as a public service provider, policymaker, public affairs manager, and public power exerciser. The public's perception and response to the epidemic are the social basis for prevention, control, and resolution of the crisis. The media also plays an integral role as an avenue for information transmission and risk communication. Overall, emergency information on public health security incidents comes from different fields, departments, and carriers. Therefore, it is necessary to strengthen the coordination and sharing of emergency information among these variable mediums. Fig. 1 defines the structure and content of the public health security emergency information for COVID-19.

Epidemic emergency information handling differs from the handling of conventional information on other public health security incidents. It requires more focus. The consistency, accuracy, and adequacy of emergency information are vital to decision-making and actions taken during such incidents. Effective emergency information should be accurate, simple, clear, and authoritative. Official emergency information should be universally communicated by agencies with more authority.

As shown in Fig. 2, during the outbreak of COVID-19, the National Health Commission established a 32-unit organization to prevent the epidemic outbreak. Under this structure, responsibilities for epidemic prevention, control, medical treatment, scientific research, and materials are clearly outlined. This creates an effective support structure for epidemic response. The organizational structure of this COVID-19 prevention and control team is not constrained by the traditional administrative systems. Its structure is event-oriented and efficient operations focused. It can improve the accuracy and credibility of emergency information while also curbing misleading information. Horizontal communication no longer requires permission from administrative superiors to ensure the efficiency of emergency information transmission.

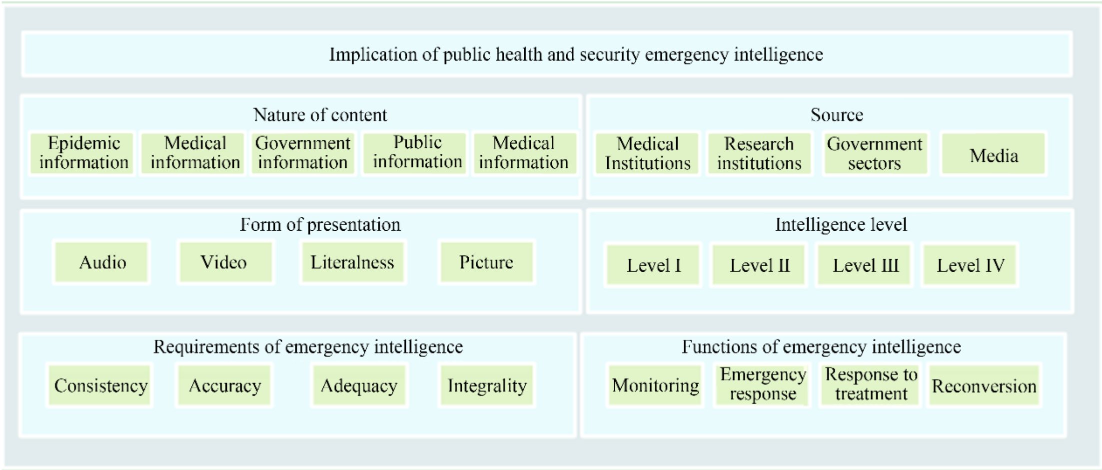

Fig.1. Structure and content of public health and safety emergency intelligence.

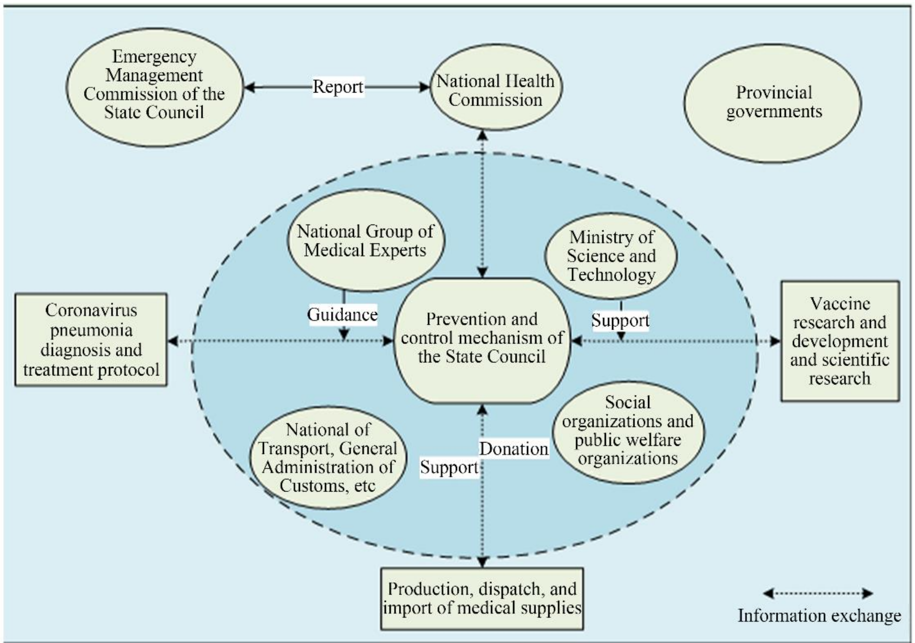

Fig.2. Organizational structure of public health and safety emergency intelligence during the COVID-19.

3 Blockchain sharing model of public health safety emergency information

This study designed a collaborative model for sharing public health security emergency information based on a consortium chain. The model addresses the difficulty and inefficiency in information sharing across regional departments. As shown in Fig. 3, a hierarchical sidechain sharing model was established to reduce the amount of data transmission in the main chain and improve the efficiency of emergency intelligence sharing. Emergency information sharing data scale, scope, and timeliness are the core of public health security emergency management. This study considers that the main information flow is stored in the sidechain of the province where the event occurs, while the information flow across provinces and cities uses the event summary as the main information flow.

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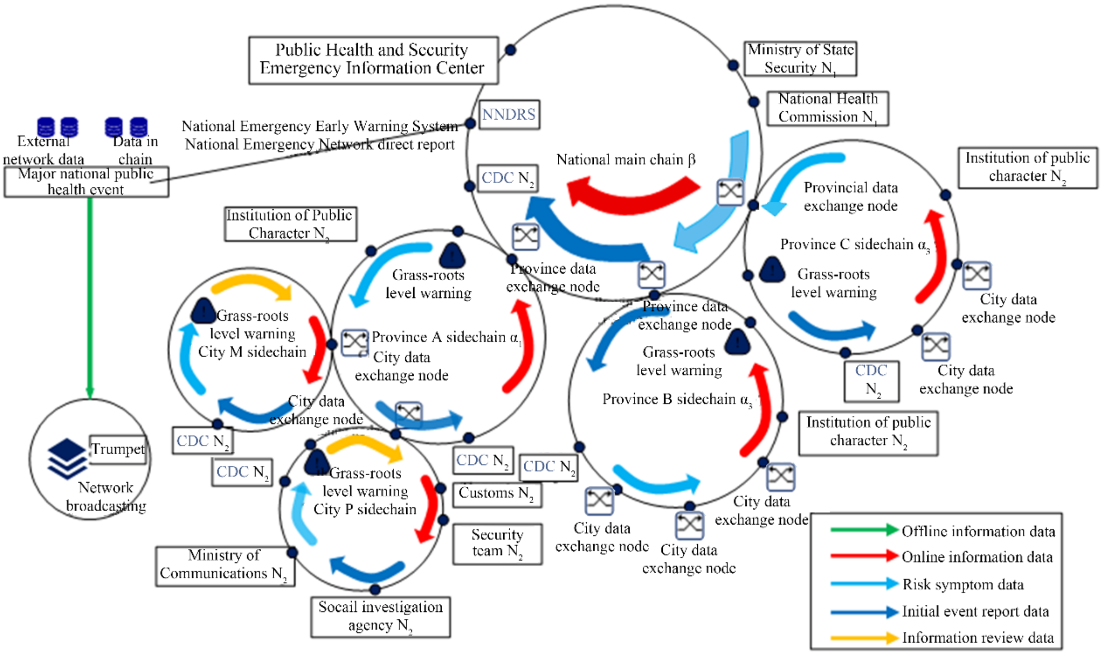

Fig.3. A collaborative public health and safety emergency intelligence sharing model based on consortium blockchains.

Note: NNDRS refers to Chinese infectious diseases reporting system; CDC refers to Center for Disease Control.

The sidechains of each province and city are established according to their emergency intelligence agencies. For example, the sidechain of city P of province A is composed of the municipal health commission, public institutions, transportation departments, and social organizations. The upload of emergency information from each agency to the main consortium chain occurs through data exchange at each level. Real-time intelligence and risk data can be queried on the sidechain for each province and city. All data is reviewed on the sidechain after being uploaded for the first time. After confirming the main chain, the data are broadcast to the entire network and become offline intelligence data on the chain.

The municipal sidechain has common nodes (N_3) and management nodes (N_2). General nodes such as transportation, customs, and other departments can provide the latest personnel information flow. The general nodes are responsible for collecting, uploading, and sharing emergency information. Management nodes—such as the Ministry of Security and the Health Commission—are responsible for verifying and endorsing the information uploaded in the municipal sidechain. Their functions are compatible with the functions of ordinary nodes. The emergency information uploaded by the municipal node is stored in the municipal sidechain, and only summary information is uploaded to the provincial sidechain.

The provincial sidechain has common nodes (N_3) and management nodes (N_2). The province's emergency information uploaded by different counties and cities is collected from the provincial sidechain. The management node in the provincial sidechain can search for and consult the province's emergency information. They can then apply it and check it against the relevant emergency information of other provinces and cities through the provincial data exchange node.

The national main chain contains management nodes (N_2) and master management nodes (N_1). A summary of the emergency information of different provinces and cities is uploaded to the main chain via the sidechain data exchange node. The master management node in the main chain is responsible for verifying, reviewing, and authorizing the identity of the management nodes in the sidechain. The master management nod sets the emergency management rights of each node in the sidechain through the smart contract. The verified nodes can search, download, and analyze relevant public health emergency information in the main chain. The management node in the main chain is also responsible for the daily maintenance of the entire consortium main chain.

3.1 Public health emergency information collaborative sharing consortium chain

The architecture of the public health emergency information sharing consortium chain designed in this study is shown in Fig. 3. It consists of a platform for the emergency information sharing consortium chain, emergency information sharing sidechain α_i, and emergency information main chain β. The data layer collects emergency intelligence data shared by the business platforms of public health emergency intelligence agencies. It also collects data from the basic data platform centers of other government departments. Each business data platform provides the original emergency information required for the collaborative sharing platform to disseminate public health emergency information through application program interface docking. Each region's information is uploaded to sidechain α_i through the emergency intelligence sharing platform. The information uploaded by each region's individual sidechain α_i constitutes the data-sharing platform. The sidechain information summary of these regions is packaged and uploaded to the main chain β, $\beta = (\alpha_1, \alpha_2, \alpha_3...)$.

After the transaction node initiates a transaction on the data-sharing platform, the node in the corresponding region initiates a request to the sidechain network. The endorsement node then endorses. The sorting node then sorts. The corresponding block is generated for bookkeeping. The sidechain structure of public health emergency intelligence sharing is shown in Fig. 4. After information on the emergency information sharing platform is uploaded to the sidechain, the transaction node submits the transaction request. The endorsement node then verifies the request after obtaining the transaction request from the transaction node. The endorsement node also verifies the format of the request, whether the transaction signature is valid, whether the submission has written permission, and whether it is repeated. Following the verification step, the endorsement node executes the smart contract submitted in the transaction to generate a read/write set, signs the generated read/write set, and returns the execution result to the transaction node. After the request is issued, the transaction node is always in a "waiting" state. After receiving the response from the endorsement node, the transaction node conducts signature verification of the message. Subsequently, a formal transaction will be generated, broadcast to the ranking node for sorting, and then the corresponding block will be generated and broadcast to the master node. After receiving emergency information sent by the endorsement node, the account node verifies the block's validity and submits it to the local account to complete the storage function. Each sidechain uploads the main information to the main consortium chain to complete the emergency information sharing process.

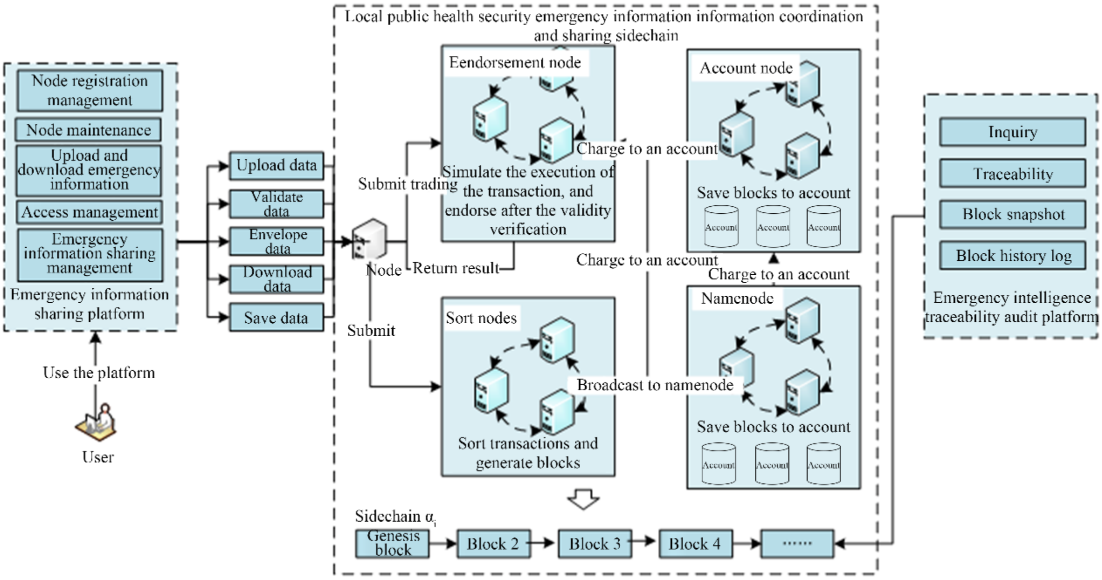

Fig.4. Public health emergency intelligence sharing sidechain.

3.2 Structure of public health emergency information block

The block of the emergency consortium blockchain is mainly composed of two parts: the block head and block body. A blockchain is composed of blocks. Each block records the identification number of the previous block. Each block body contains a quantity of emergency intelligence information and is the actural carrier for storing the blockchain data. The public health emergency intelligence consortium blockchain contains information with different attributes. This includes event information (*a*), public opinion information (*i*), information timeliness (*t*), information security level (*s*), and information emergency response level (*c*). Message body $\delta = \{a, i, t, s, c\}$. Event information is used to record specific event information when public health safety events occur. This includes the time, place, people involved, event spread scope, and main information. Public opinion information is used to record

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pertinent public opinion information and discussions before and after public health safety events. It also records the emotional state and intensity of the public and emergency victims. Timeliness of information is vital for emergency responses to the occurrence and spread of public health security events. General emergency information is the latest information regarding the event. The active management node has the highest number of emergency management rights. Different information emergency response levels are set according to a specific event situation—the influence and scope of public health security events. In addition, all the information in the message body is uploaded to the sidechain for preservation. In the sidechain, main information like the event's time and place are uploaded to the main consortium chain. The consortium chain can reduce storage pressure on the main chain while retaining the primary information.

4 Public health emergency information sharing process

The collaborative sharing of emergency intelligence based on a consortium chain has three main participants in this study: primary management nodes N_1, management node N_2, and common node N_3. The shared sidechain of each region contains two node types: the management and the common node. Fig. 5 illustrates the role of the consortium chain throughout the process of emergency information circulation. Intelligent information sharing is divided into three stages: emergency preparedness, response, and recovery. This enables the autonomous collaborative sharing of information under different emergency conditions across different periods.

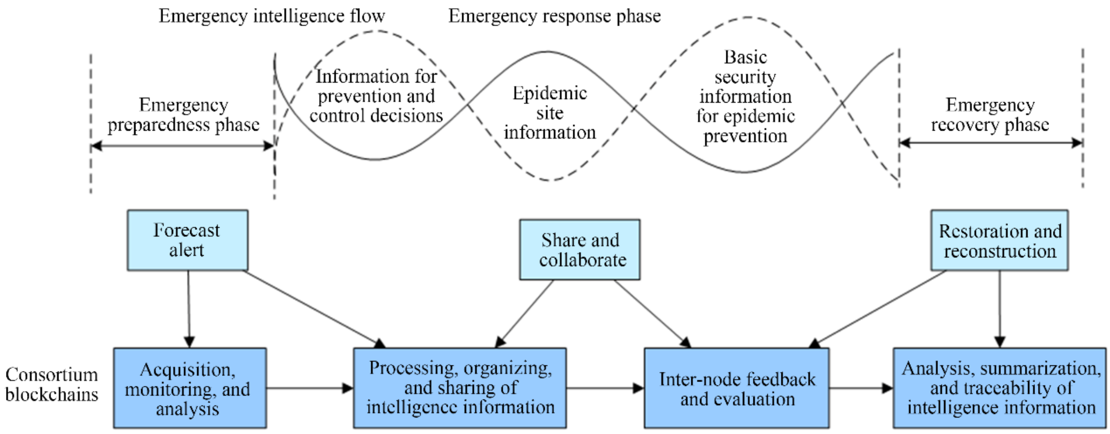

Fig.5. Flow of emergency intelligence in consortium blockchains.

The emergency preparedness phase happens during the incubation and onset of an epidemic. Government departments, online platforms, and health departments can be relied upon to monitor the risks that the epidemic may cause. This includes utilizing various intelligence sources such as personal behavior data, media opinions, and databases. Each intelligence source can serve as a node in the consortium chain. The emergency preparedness stage can monitor, collect, and analyze epidemic intelligence in real time based on all kinds of data uploaded to the consortium chain. This enables users to predict the probability of an epidemic and controls the scope of impact.

During the emergency response phase of the rapid epidemic outbreak, prevention and control shifts from early warning and prediction to multidirectional prevention and control. All participating nodes in the consortium chain jointly carry out epidemic prevention and control. Through platform system link, large-scale and multidimensional cooperation can be enacted to provide effective support for medical assistance, vaccine research and development, materials allocation, and public opinion guidance.

In the emergency recovery stage, the scope of the epidemic was well controlled. In this stage, the causes, pathways, and effective prevention measures for the spread of the epidemic can be analyzed based on the real-time sharing of emergency intelligence data on the consortium chain. Information on social governance can be summarized and extracted to provide effective support to prevent and control future epidemic events.

Hence, the main role of the emergency information consortium chain in information sharing includes the following.

(1) Uploading and verifying emergency intelligence information: Deal node N_e is the source of sidechain emergency information. Environmental, time-based, and other intelligence are collected through the emergency information sharing platform and uploaded to the sidechain α_i. Management node N_2 in the corresponding areas

validates and endorses the authenticity and validity of this message. The verified information is then uploaded to the sidechain, and the main event information is uploaded to the main consortium chain.

(2) Sharing emergency information: The main chain stores the uploaded main event information, categorizes the intelligence information access permission, and then broadcasts it to the nodes with permission. Any node with permission can query the summary information of the event.

(3) Emergency intelligence information, permission management, and downloads: The emergency information uploaded to the sidechain is disclosed to the corresponding node according to the permission level and provides a query function. N_f represents any node that wants to query and download detailed information. For example, if the node of province A wants to query information on province B's sidechain, N_f should first send a request to the main chain. After permission verification is granted, province B's sidechain information can be downloaded.

(4) Traceability of emergency information: The emergency intelligence information uploaded to the sidechain by each node is bound to the Merkle tree and synchronized to the main consortium chain of the system. It can be used as the information's traceability verification code to verify whether the emergency intelligence information has been tampered with. Meanwhile, sources of emergency intelligence information can also be held accountable in the event of problems.

5 Nanjing epidemic scenario simulation as an example

Based on the epidemic development in Nanjing from July 20, 2021, to August 21, 2021, we analyzed the "five situations" during the development period. We used the model in this study to simulate the emergency information management scenarios and verify the model's efficiency.

On July 20, nine positive samples were found during regular nucleic acid testing by the staff at Lukou International Airport. The common node—Lukou International Airport Epidemic Prevention Task Force—immediately uploads information to the Nanjing sidechain as part of the upload stage. The municipal management node—Nanjing Municipal Health Commission—organizes experts to verify and endorse the epidemic information (number of confirmed cases, locations, times, and travel trajectories) and stores it while uploading summary information to the Jiangsu sidechain. The management node—Jiangsu Provincial Health Commission—uploads it to the main chain. The National Health Commission broadcasts the information across the network after verifying the management node's information. At this time, all Municipal Health Commissions were informed of the news. By storing and querying information broadcast across the network, they were informed of the epidemic spread in real-time in terms of geography and time. Before the staff activities at Lukou International Airport resumed, timely measures were taken to control population movement. Isolation, nucleic acid testing, medical treatment, and environmental disinfection were also conducted in affected areas. Citizens in different areas consciously took initiatives for group prevention and control. The scenario simulation process showed that the spread of the epidemic was greatly reduced. Fig. 6 shows a flow chart of the simulation for emergency outbreak information in this model.

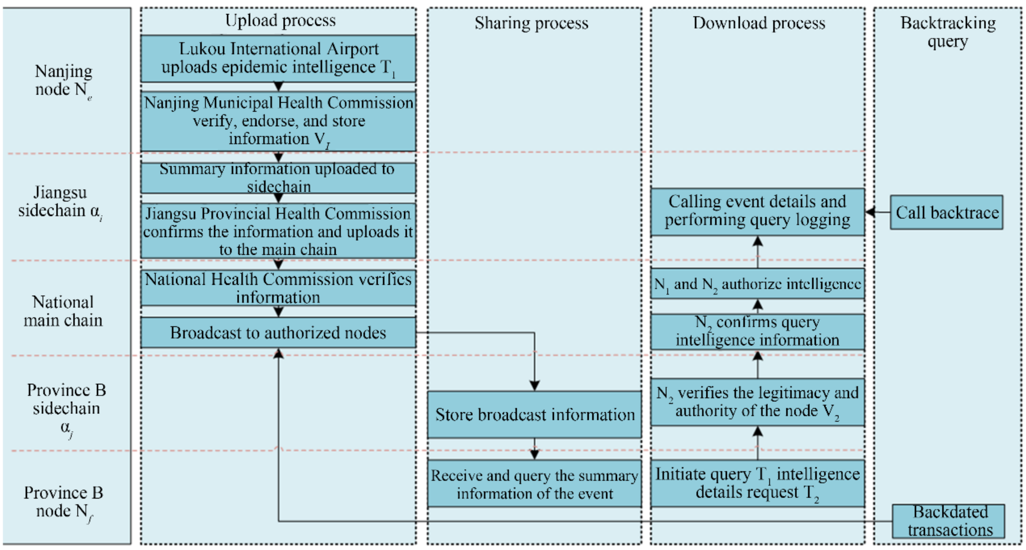

Fig.6. Nanjing epidemic emergency intelligence sharing process.

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Fig. 7 shows the "five situations" trend expressed by a proportion of the keywords—"five situations"— searched through text mining in Weibo, WeChat, and Douban during the study period during epidemic development. Government departments (political information), health departments (medical information), and online platforms (public sentiment and opinion) paid much attention to the developing epidemic situation during the incubation and outbreak periods. As a result, the epidemic was well controlled during the emergency recovery phase, as noted in public and media-based sentiments. The "five situations" show a trend of "phase growth and rapid fading."

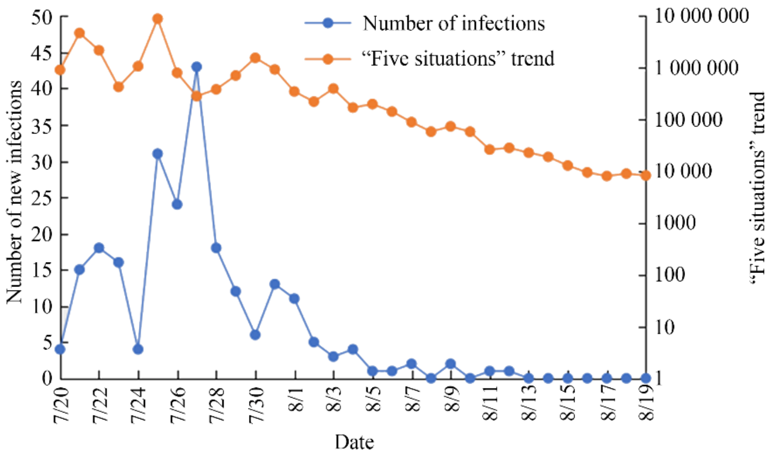

Fig.7. Analysis of five situations data during the development period of the epidemic.

The transaction per second and information delay tests of the consortium blockchain system in this study were carried out to verify the efficiency of this study's model. As shown in Fig. 8a, the number of messages is confirmed between the design time 0–500s. The transactions per second (TPS) were calculated based on the number of confirmed messages. According to the experimental tests, the throughput of this model can be stabilized at above 200 TPS. This throughput rate can efficiently transmit public health emergency information to meet the requirements of public health emergency information collaborative sharing. This model takes 30 ms to process a transaction contract. The average delay in processing a piece of information sent from a normal node to the main chain is 232 ms, except where there was good network bandwidth. The connectivity between nodes in the distributed network and connection stability also affect the information delay. The gas price is usually expressed as a transaction fee in a blockchain. For the model presented in this study, gas price is the urgency weighting of a piece of information. The higher the gas price, the stronger the urgency, and the shorter the confirmation time. However, the gas price is not as high as possible. The experimental diagram showing gas versus the confirmation times for this model is shown in Fig. 8b. When it reaches the apex, the confirmation time will increase.

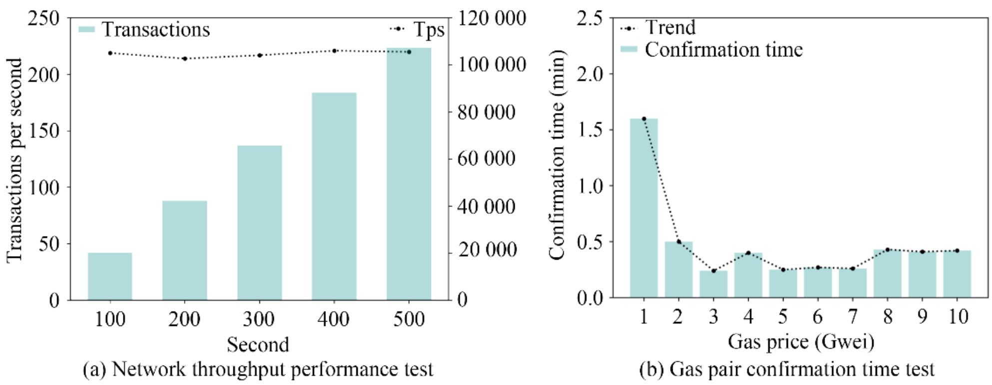

Fig.8. Performance test of emergency intelligence sharing model.

6 Conclusion and suggestions

Public health emergency information, such as the COVID-19 pandemic, has complex characteristics. This information includes multiple aspects, dynamic changes, rapid dissemination, differential distribution, and unpredictable hazards. Authenticity, validity, and real-time information are key factors in supporting the construction of emergency decision-making systems. Therefore, the core requirement of public health emergency information management in China is safe, efficient, and real-time information sharing and exchange. It is desirable to construct a new system that meets the emergency management needs for major epidemic prevention and control. This study analyzed the structural features of public health security emergency information under the COVID-19 pandemic. We optimized traditional public health emergency information transmission mode using blockchain technology and proposed a collaborative, hierarchical emergency information-sharing model based on consortium blockchains. We broke down the segmentation barriers in emergency information-sharing mechanisms, used sidechains to reduce the data throughput of the main consortium blockchains, and ensured their efficiency. We designed a process for uploading, sharing, downloading, and backdating emergency information. Through this, we secured the traceability and accountability of information through node authority control. To further improve the public health security and emergency information-sharing system in China, the following measures are proposed:

First, optimizing the emergency information system with a decentralized, flattened, and grid-based structure is necessary. It is necessary to construct a technical mechanism for identifying accuracy, reliable safety, and authenticity confirmation of the information system. Furthermore, information response and collaboration speed must be enhanced, and information and decision-making response synergy must be realized.

Second, we should create a public health risk-prevention mechanism. It should cover risk prediction, real-time monitoring, and information integration functions to achieve effective monitoring and crisis prediction. Examples include real-time data monitoring using the State Council Big Data Itinerary Card or Health QR codes from provinces and cities, regular nucleic acid testing, and environmental disinfection measures in infection-prone areas such as airports, train stations, and hospitals. Potentially infected populations should be able to upload their information to the blockchain in a timely fashion to ensure real-time information sharing.

Third, an emergency management information sharing model should be established to detect unexplained infectious diseases such as COVID-19. It is necessary to improve data access and sharing mechanisms between government departments, cities, and regions and strengthen cross-departmental, cross-field, and cross-regional coordination. It is necessary to construct a bottom-up response mechanism. The public should be urged to upload information related to the epidemic promptly. This may include overseas residency and routes to medium- and high-risk areas within 14 days of infection. This enables the recording of epidemic contact tracing information. The public can see the relevant information via the emergency information-sharing model and take appropriate precautions.

Fourth, we should integrate this system into the entire public health emergency response process. This can enable the construction of a “multiple situations” analysis framework based on public sentiment and opinion and epidemic, medical, and political information. It is necessary to integrate the emergency risk information of various departments using blockchain technology and build an information-sharing platform. This can improve the level of public safety, risk monitoring, and early warning projections for major infectious diseases, such as COVID-19.

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