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Theoretical and practical research on regional cooperative governance mechanism applying social network analysis in the context of human health community

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SUMMARY: *Under the background of the construction of human health community, regional health governance is facing the realistic situation of risk cross-domain diffusion, subject collaboration dispersion and resource linkage lag. Existing studies mostly focus on single disease or sectoral collaboration, and there are few discussions on the structure of regional cooperation network and its governance transformation. This paper uses social network analysis method to construct a weighted directed network covering health administration, disease control and prevention, medical institutions, grass-root organizations and collaborative support subjects, and designs information sharing, resource collaboration, risk linkage and feedback update mechanisms. Verified with the collaboration data of five cities in a province, the number of collaboration relationships increased from 426 to 512, the network density increased from 0.128 to 0.186, and the resource arrival rate increased to 86.5%. The research shows that this method can provide quantitative identification and practice optimization path for regional health cooperative governance.*

KEYWORDS: *Human health community; Social network analysis; Regional cooperative governance; Healthy coordination mechanism*

1 Introduction

Global public health risks, accelerated population movements, changes in the ecological environment and uneven regional development make health problems gradually go beyond the governance boundaries of a single administrative region and a single department. Prevention and control of infectious diseases, management of chronic diseases, allocation of health resources, emergency response to public health emergencies and prevention of ecological health risks often involve multiple subjects such as medical and health care, disease control, civil administration, transportation, education, ecological environment, market supervision and community organizations. The concept of human health community emphasizes the overall relationship between human health, social system, ecological environment and regional collaboration. Its governance focus is no longer limited to the supply of medical services, but turns to the collaborative governance process of cross-departments, cross-regions and cross-levels. In this context, whether the regional cooperative governance mechanism can form stable subject connection, clear division of

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responsibility and continuous information sharing directly affects the actual effect of health risk identification, resource scheduling and policy implementation.

The existing public health governance system has accumulated more collaborative experience in practice, such as joint prevention and control mechanism, medical prevention integration platform, regional medical alliances, healthy city construction, and multi-sector special actions. These mechanisms have improved the organizational capacity of regional health governance to a certain extent, but there are still problems such as loose collaboration, insufficient information circulation, excessive burden on core nodes, insufficient participation of peripheral regions, and poor connection of cross-domain responsibilities. Especially in the process of complex health risk diffusion, the risk propagation path does not completely obey the administrative boundary, and population migration, transportation network, industrial links and ecological environment changes will change the scope of regional health governance. If the analysis is still based on static administrative hierarchy or single department function, it is difficult to accurately identify key subjects, weak relationships and coordination block links in regional cooperation.

Social network analysis provides a computational analysis tool for understanding regional health cooperative governance. This method can abstract subjects such as government departments, medical institutions, centers for disease control and prevention, scientific research organizations, community platforms and social organizations as network nodes, and transform behaviors such as policy consultation, data sharing, resource support, joint monitoring, referral collaboration and emergency linkage into network relationships. The cooperation structure is revealed by indicators such as density, centrality, structural hole, cohesion subgroup and network efficiency. Compared with general descriptive research, social network analysis can transform complex collaborative relationships into quantifiable, comparable and traceable network graphs, and make regional cooperative governance move from empirical judgment to data support. With the continuous accumulation of government data platforms, public health information systems, electronic medical records, emergency dispatch logs and regional collaboration records, the use of computer technology to clean multi-source data, relationship extraction, graph network modeling and dynamic visualization analysis also provides a new method basis for the study of health community governance mechanism.

Related research has focused on multi-sector Health alliances, inter-organizational collaboration networks, One Health governance framework, health equity cooperation mechanism, and internal process improvement in medical organizations [1-8]. These results show that the effectiveness of health governance depends not only on the capacity of individual institutions, but also on the strength of inter-subject connections, network locations, and coordination rules. In recent years, studies on cross-sectoral action partnerships, global health networks, access to medicines subject networks, and health team collaboration technologies further show that there is a close link between network structure and governance performance [9-15]. However, from the perspective of human health community, the research that combines regional cooperative governance mechanism, social network analysis indicators and computerized practice verification is still relatively insufficient. Some studies focus on theoretical explanation and lack of quantitative identification of subject relationship structure. Some studies focus on a single disease or a single organization scenario, which is difficult to reflect the complexity of regional health governance. Although some studies use network analysis methods, they do not fully discuss how to optimize governance mechanisms based on network results.

Based on this, this paper focuses on the construction and verification of regional cooperative governance mechanism in the context of human health community. This study

included the regional health governance subjects and their collaboration behaviors into the social network analysis framework, and analyzed the operational characteristics of regional health cooperation networks by constructing the subject network, calculating structural indicators, and identifying core nodes and weak relationships. On this basis, this paper further designs information sharing, resource collaboration, risk linkage and feedback optimization mechanisms, so that the network analysis results can be transformed into executable governance schemes. In order to enhance the operability of the research, this paper introduces the computer data processing flow, carries out standardized coding, relationship matrix construction and network visualization expression of multi-source collaboration records, and compares the changes of network structure and collaboration performance before and after the optimization of governance mechanism in the practical verification part.

The follow-up contents of this paper are arranged as follows: Section 2 combs the relevant research on human health community and regional cooperative governance; Section 3 constructs the regional cooperative governance mechanism based on social network analysis, including the construction of regional health cooperative subject network and the design of governance mechanism. Section 4 carries out the practice verification and result analysis of regional health cooperation network, focusing on the characteristics of network structure and the optimization effect of governance mechanism. Section 5 summarizes the conclusions and proposes future research directions.

2 Research on human health community and regional cooperative governance

In recent years, the research on human health community, cross-sectoral health collaboration and regional cooperative governance has gradually shifted from single public health supply to multi-agent network collaboration. Health issues have cross-domain mobility and system relevance. Disease prevention and control, health resource allocation, environmental risk response and health equity improvement all require the participation of government departments, medical institutions, scientific research organizations, community subjects and social organizations. Therefore, how to identify the collaborative relationship between subjects, judge whether the cooperative network is stable, and further form an executable regional governance mechanism has become an important issue in the research of public health governance and public management.

Heeren et al. [1] applied the network analysis method to the formation and sustainability assessment of multi-sector alliances, and pointed out that the connection frequency, resource exchange and relationship stability between alliance members would affect the long-term operation of cooperative organizations. This study provides a method reference for measuring the relationship between the subjects of regional health cooperation, but its discussion focus is mainly on the development process of the alliance, and the analysis of responsibility sharing and policy linkage in cross-regional governance is still insufficient. White et al. [2] took the collaboration among organizations as the object and used social network analysis to explore the organizational relationship structure in the improvement action of social connection, indicating that the central subject of the network can promote information diffusion and collaborative mobilization. However, this study focuses more on the internal collaboration of social service organizations, and does not reveal the complex relationship between multi-level governments and medical and health institutions in the context of health community. Such et al. [3] sorted out the cross-sectoral cooperation in the governance of population health and health inequality in high-income countries from the perspective of complexity, and

emphasized that health governance is not a linear administrative process, but the result of multi-agent interaction and institutional environment. This achievement expands the theoretical basis of regional cooperative governance, but lacks the support of quantifiable network structure indicators.

In the research related to the human Health community, the One Health framework has received extensive attention. Ghai et al. [4] proposed a generalizable One Health zoonoses control framework, which integrates human health, animal health and ecological environment into a unified governance vision and emphasizes the importance of cross-sectoral monitoring and collaborative response. Hernandez et al. [5] used social network analysis to support the network construction of emerging female leaders in the global health field, indicating that connectivity and network support would affect the cultivation of health leadership. Paterson et al. [6] used social network analysis as an action research tool and pointed out that network methods can not only present subject relationships, but also promote collaborative reflection in practice. Onasanya et al. [7] analyzed the social network structure of the schistosomiasis control project in Nigeria, and found that the strength of the links between local governments, health departments and implementing agencies would affect the efficiency of the elimination plan. These studies show that health governance needs to be further shifted from "institutional capacity" to "relational capacity", but most of the achievements are still focused on specific diseases, specific organizations or specific projects, and there is still room for further deepening of the overall governance mechanism of regional health communities.

With the increasing complexity of medical and health governance, the operation mechanism of collaborative governance network has become a research hotspot. Belrhiti et al. [8] sorted out the dynamics of collaborative governance in medical networks through a scope review, and pointed out that trust, power distribution, common goals and institutional arrangements would affect the quality of cooperation. Asirvatham et al. [9] summarized the methods of evaluating cross-sectoral action partnerships and emphasized that the governance of social determinants of health needs to take into account both process evaluation and outcome evaluation. Clifford Astbury et al. [10] used mixed-method network analysis to study wildlife trade governance and prevention of emerging zoonoses, revealing departmental barriers and power differences in transnational organization networks. Francis et al. [11] discussed the application of social network analysis in the process improvement of medical organizations, indicating that network indicators can help identify communication blocking points and process coordination weaknesses. Ezenwa et al. [12] analyzed the team science network of CaRE2 Health Equity Center, and further explained that interdisciplinary team cooperation can present its knowledge integration process through the network structure. These studies provided direct reference for this paper to identify the structure of regional health cooperation networks. However, in terms of governance mechanism optimization, most literatures still remain at the level of network description or organizational diagnosis, and have not fully explained how the network analysis results are transformed into regional collaboration rules.

In addition, some studies have begun to apply social network analysis to medical resource accessibility, health policy implementation, and collaborative technical support. Lankarani et al. [13] proposed a method based on social network analysis to analyze the subject network related to the accessibility of anticancer drugs in Iran and reveal the structural position of different institutions in drug governance. Lagby et al. [14] systematically reviewed the role of emerging technologies in medical team collaboration, indicating that digital platforms, information systems and intelligent tools can improve team communication efficiency. Tancred et al. [15] discussed the cross-sectoral cooperation path of health manpower from the perspective of "integrating health into all policies", and pointed out that health governance

requires collaborative arrangements among policies, organizations and human resources. La Grouw et al. [16] analyzed the collaborative governance mode in big problems from the perspective of daily practice, indicating that the governance mechanism is not only reflected in the macroscopic system design, but also in the subtle practices such as meeting consultation, data sharing and task cohesion. These studies suggest that regional cooperative governance cannot only rely on institutional initiatives, but also need data flow, process records and dynamic feedback supported by computer platforms.

In view of specific health issues, Bakhtiari et al. [17] used stakeholder analysis and social network analysis to study cross-sectoral collaboration in the risk factor management of noncommunicable diseases in Iran, and found that the participation degree of key sectors would affect the implementation effect of policies. Schorderet et al. [18] proposed a research program of social network analysis on home nursing collaborative practice, which provided design ideas for the measurement of subject interaction in nursing services. Mwatondo et al. [19] analyzed the global One Health network and its cooperation expansion, and pointed out that global health cooperation shows a rapid growth trend, but network expansion may also bring an increase in coordination costs. Larkins et al. [20] conducted a network analysis of One Health practice in Laos, indicating that national-level health collaboration needs to establish a connection between formal system and actual interaction. Hegewisch-Taylor et al. [21] studied the governance and implementation challenges of One Health in Mexico, and pointed out that sector segmentation, uneven resources and differences in implementation capabilities are still important obstacles in the construction of health communities.

In summary, existing studies have provided theoretical and methodological basis for regional cooperative governance in the context of human Health community from the perspectives of multi-sector alliance, One Health framework, medical collaborative network, health equity teamwork and specific disease governance. In order to further present the core views of different research directions and their enlightenment to this paper, this paper summarizes the relevant literature into six categories: multi-sector Health alliance and organizational collaboration, One Health and human health community, application of social network analysis method, collaborative governance mechanism and performance evaluation, network governance in specific health issues, and health collaboration supported by digital technology. The details are shown in Table 1.

Table 1: Summary of related studies

Research Direction	Representative Studies	Main Viewpoints	Implications for This Study
Multi-sector Health Alliances and Organizational Collaboration	Heeren et al. [1]; White et al. [2]; Such et al. [3]	Health collaboration depends on actor connections and resource exchange	Shift from departmental capacity to network-based collaboration analysis
One Health and Human Health Community	Ghai et al. [4]; Mwatondo et al. [19]; Larkins et al. [20]; Hegewisch-Taylor et al. [21]	Health governance should integrate humans, animals, and ecosystems	Focus on cross-sectoral, cross-regional, and cross-system relations
Application of Social Network Analysis	Hernandez et al. [5]; Paterson et al. [6]; Onasanya et al. [7]; Francis et al. [11]	Network analysis identifies core nodes and weak ties	Convert governance actors into computable network nodes
Collaborative Governance Mechanisms and Performance Evaluation	Belrhiti et al. [8]; Asirvatham et al. [9]; La Grouw et al. [16]	Collaborative performance is shaped by trust, power, and shared goals	Translate network results into governance optimization rules
Network Governance in Specific Health Issues	Clifford Astbury et al. [10]; Ezenwa et al. [12]; Lankarani et al. [13]; Bakhtiari et al. [17]; Schorderet et al. [18]	Disease governance and care collaboration show network features	Validate structural indicators and governance outcomes
Digital Technology and Health Collaboration Support	Lagby et al. [14]; Tancred et al. [15]	Digital technologies improve communication and collaboration	Combine data processing, network modeling, and visualization

Table 1 shows that existing studies have fully demonstrated the important role of network relationships, cross-sectoral cooperation and digital technology in health governance, but there are still three shortcomings: first, most studies focus on a single disease, a single project or a single organizational scenario, and insufficient analysis of multi-agent, multi-level and multi-task collaboration in regional health communities. Second, some studies use social network analysis as a static description tool, lacking mechanism design based on network results. Third, a complete closed loop has not been formed between computer data processing, relationship matrix construction, network visualization and governance performance evaluation. Based on this, this paper introduces social network analysis method into the study of regional health cooperative governance mechanism, and constructs a regional cooperative governance analysis framework with both theoretical explanatory power and practical operation through multi-source collaborative data standardization, subject relationship network modeling, network structure index calculation and mechanism optimization effect verification.

3 Construction of regional cooperative governance mechanism based on social network analysis

This section constructs a regional cooperative governance mechanism for the human health community. The mechanism does not simply describe the administrative responsibilities of various health governance subjects, but integrates regional government departments, medical and health institutions, disease control institutions, scientific research institutions, community organizations, social service institutions and digital platforms into a unified network analysis framework. Through data collection, subject identification, relationship extraction, network modeling, structure measurement and governance feedback, etc. Form a collaborative governance path that can be calculated, interpreted and adjusted. The core idea is to transform the "cooperative relationship" in the health community into the "nodes and edges" in the network, and then identify key subjects, collaborative channels and weak links with the help of social network analysis indicators, so as to provide a basis for regional health policy linkage, resource scheduling and risk emergency response.

Figure 1: Overall architecture of regional health cooperation governance mechanism

As shown in Figure 1, the regional cooperative governance mechanism constructed in this paper consists of five functional modules: health governance data access module, cooperative subject identification module, collaborative relationship modeling module, network structure analysis module, and governance mechanism feedback module. The health governance data access module is responsible for collecting regional health statistics, public health event reports, medical alliance collaboration records, cross-departmental meeting minutes, emergency resource allocation logs and health service platform data. The cooperative subject identification module is used to confirm the types, hierarchical attributes and functional roles of institutions participating in regional health governance. The collaborative relationship modeling module transformed the behaviors of joint consultation, information sharing, referral collaboration, material support, risk reporting and project co-construction into network edges. The network structure analysis module calculates the connection strength, center position, collaboration density and relationship stability. The feedback module of governance mechanism adjusts responsibility allocation, information channel and resource linkage mode according to the analysis results.

3.1 Construction of regional health cooperation subject network

The construction of regional health cooperative agent network is the basic link of our method, and its task is to organize the multiple participants and their collaborative behaviors in the human health community into a computable network structure. The subjects of regional health governance are obviously heterogeneous, including provincial, city, county and other government departments at different levels, as well as hospitals, centers for disease control and prevention, primary health service institutions, scientific research institutions, community organizations, social assistance institutions and digital health platforms. Vertical instruction transmission, horizontal resource mutual assistance and cross-regional data sharing relationship may occur between different subjects through information platforms. Therefore, a weighted directed network is used to describe the regional health cooperation structure in this paper. Let the regional health cooperation network be:

$$G_t = (V_t, E_t, W_t) \tag{1}$$

Where, G_t represents the regional health cooperation network at time t, V_t is the set of governance subjects, E_t is the set of collaborative relationships between subjects, and W_t is the set of collaborative relationship weights. This representation can simultaneously reflect the number of subjects, the connection direction and the cooperation intensity, and is suitable for describing the multi-level interaction in regional health governance.The set of governance subjects is defined as follows.

$$V_t = \{v_1, v_2, \dots, v_n\} \tag{2}$$

where, v_i represents the ith health governance subject and n represents the total number of subjects in the network. The subject types include health administrative departments, disease control institutions, general hospitals, primary medical institutions, emergency management departments, civil affairs departments, ecological and environmental departments, community organizations and data platforms. In order to avoid node duplication caused by inconsistent organization names in different data sources, this paper adopts unified social credit code, full name of organization, administrative division and business function to match, and merges abbreviation, historical name and platform registration name in the subject identification stage. The set of collaboration relationships is defined as follows.

$$E_t = \{e_{ij,t} \mid v_i \to v_j, i \neq j\} \tag{3}$$

where, $e_{ij,t}$ denotes the collaboration relationship in which agent v_i points to agent v_j. A directed edge is formed if one agent initiates information dissemination, resource support, referral collaboration, joint monitoring, or policy consultation to another agent. The processing can reflect the direction of cooperation, for example, the superior health department issues risk tips to grassroots institutions, the hospital reports abnormal cases to the disease control agency, and the community organization feedbacks the health needs of key groups to the medical institution, which can be expressed as a network relationship in different directions. In order to improve the computability of the network relationship, this paper constructs the collaborative adjacency matrix:

$$A_t = [a_{ij,t}]_{n \times n} \tag{4}$$

Here, $a_{ij,t}$ denotes whether there is a cooperative relationship between agent v_i and

agent v_j at time t. $a_{ij,t}$=1 when there are valid collaboration records between the two. When there is no collaborative record, $a_{ij,t}$=0. This matrix is the basis for subsequent centrality calculation, density analysis, and relationship visualization.

Considering that regional health cooperation is not simply with or without connectivity, this paper further constructs the weight of collaboration strength. The cooperation strength between agents is determined by the cooperation frequency, the importance of cooperation type and the time attenuation coefficient:

$$w_{ij,t} = f_{ij,t} \cdot r_{ij,t} \cdot \lambda^{\Delta t} \tag{5}$$

where $w_{ij,t}$ represents the cooperation weight between agent v_i and agent v_j, $f_{ij,t}$ represents the cooperation frequency, $r_{ij,t}$ represents the cooperation type weight, and $\lambda^{\Delta t}$ represents the time decay term. Collaborative behaviors that occur recently have a greater impact on the network structure, and collaborative relationships that occur earlier and are not sustained in the subsequent period have a correspondingly lower weight. The design can reflect the dynamic change characteristics of regional health cooperation network. The collaboration type weight is set according to the importance of the governance behavior:

$$r_{ij,t} = \sum_{k=1}^{m} \beta_k x_{ij,k,t} \tag{6}$$

where, $x_{ij,k,t}$ represent whether the KTH type of collaborative behavior occurs between agent v_i and agent v_j, β_k represents the weight of this type of collaborative behavior, and m represents the number of types of collaborative behavior. In this paper, the collaborative behaviors are divided into types such as information sharing, joint consultation, risk notification, resource scheduling, medical referral, project co-construction and emergency disposal. Among them, emergency response and resource scheduling have a great impact on regional health and safety, and can be given a higher weight. Although the frequency of general information sharing is high, the impact of single time is relatively limited, and the weight can be appropriately reduced. In order to compare the difference of cooperation strength between different subjects, this paper normalizes the original weights:

$$\widehat{w}_{ij,t} = \frac{w_{ij,t} - w_{min}}{w_{max} - w_{min}} \tag{7}$$

where, $\widehat{w}_{ij,t}$ represents the normalized collaboration weight, and w_{max} and w_{min} represent the maximum and minimum values of the collaboration weight during the sample period, respectively. The normalized weight values are more stable and convenient for horizontal comparison between different regions, different time periods, and different subject types. After node identification and edge weight calculation, this paper forms the regional health cooperation network matrix:

$$M_t = A_t \circ \widehat{W}_t \tag{8}$$

where, M_t represents the weighted relationship matrix that is finally used for social network analysis, $\widehat{W}_t$ represents the normalized weight matrix, and $\circ$ represents the multiplication of corresponding elements. The matrix not only retains the information of whether the collaboration relationship exists, but also reflects the relationship strength difference, which can be used as the data basis for the subsequent analysis of network density, centrality,

cohesive subgroup and structural hole.

Figure 2 shows the construction process of the regional health cooperative agent network. After the raw data enters the system, it needs to go through the steps of data cleaning, subject identification, relation extraction, weight calculation and matrix generation. Each step corresponds to a clear data processing task, which can ensure the traceability and reproducibility of the network construction process.

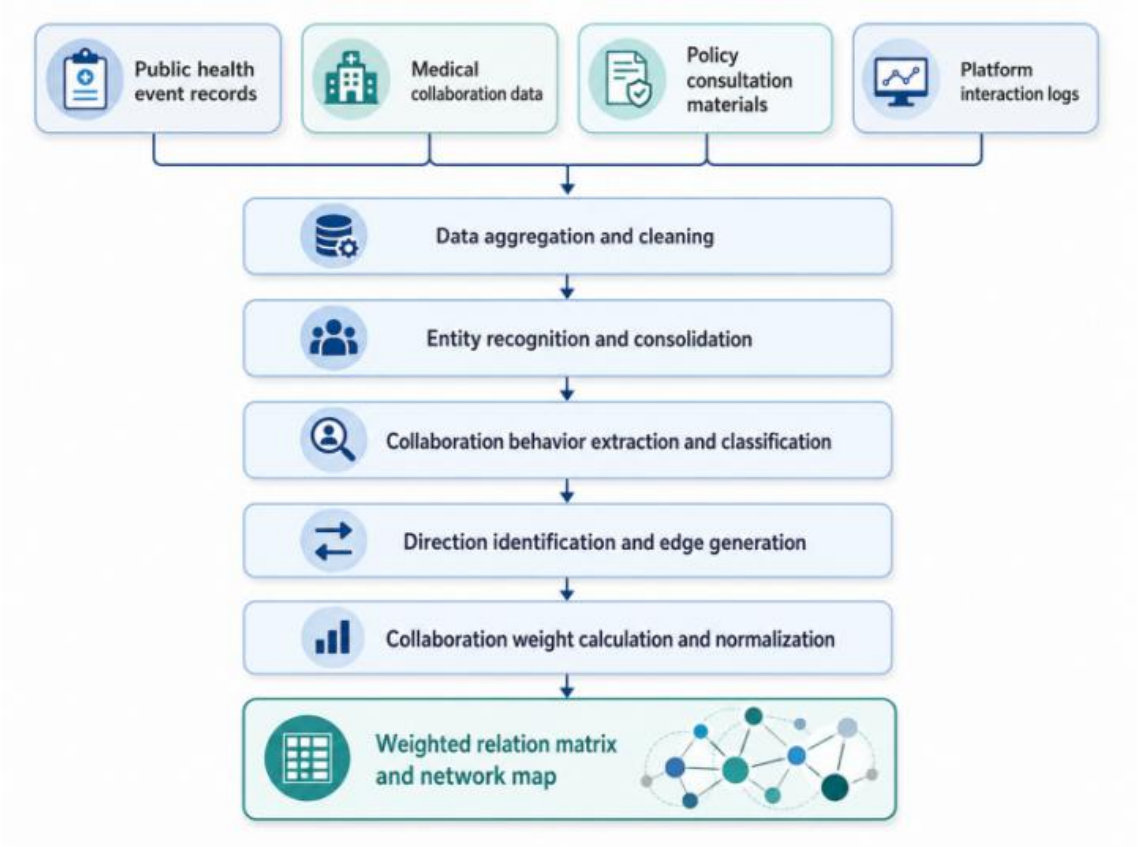

Figure 2: Construction process of regional health cooperative agent network

3.2 Design of regional cooperative governance mechanism

After completing the construction of regional health cooperation subject network, the governance mechanism design needs to further answer how the network analysis results are transformed into executable regional collaborative actions. Regional cooperative governance in the context of human health community is not a simple juxtaposition of multiple subjects, but a dynamic operating system based on health risk sharing, information exchange, resource complementarity and shared responsibility. Social network analysis method can identify the core nodes, bridge nodes, edge nodes and collaboration breakpoints in the network, but without the corresponding mechanism transformation, network indicators are still difficult to directly serve the governance practice. Therefore, based on the weighted relationship matrix formed in Section 3.1, this paper designs a regional cooperative governance mechanism composed of risk perception, information sharing, resource collaboration, linkage disposal, feedback correction and mechanism update. Its overall operation logic is shown in Figure 3.

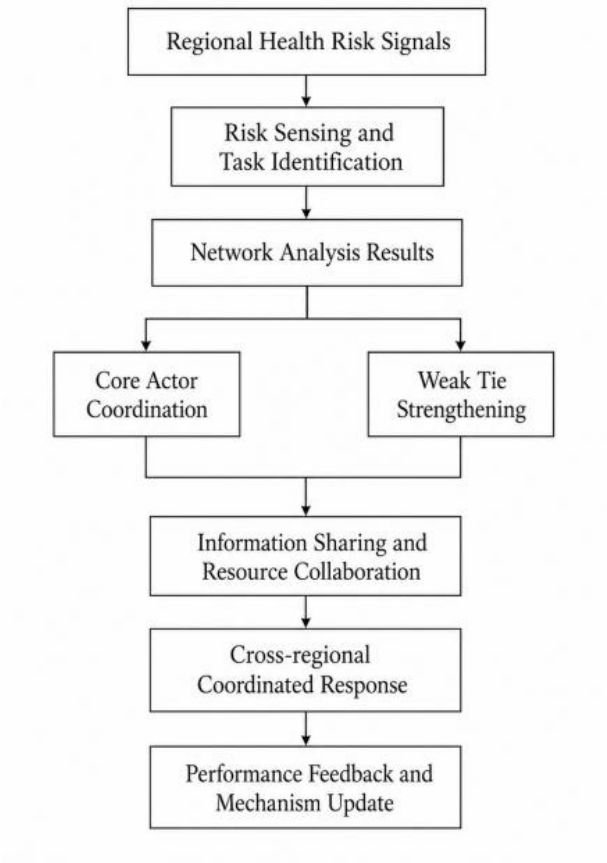

Figure 3: Operational framework of regional cooperative governance mechanism

The starting point of the mechanism is regional health risk signal identification. Risk signals include abnormal reports of infectious diseases, pressure on chronic disease management, shortage of public health resources, service needs of key populations, and health impacts caused by ecological environment changes, population movements and emergencies. After receiving the risk signal, the system does not directly assign tasks according to the administrative level, but calls the agent network constructed in the previous section to determine which agents are in the information convergence position, which agents have the resource support ability, and which regions have cooperation breaks. In this way, it can avoid excessive concentration of governance tasks in a few departments and also reduce the lag of risk response in peripheral areas. In order to determine the task priorities of different agents in cooperative governance, this paper constructs the agent collaborative priority function:

$$P_{i,t} = \alpha_1 C_{i,t} + \alpha_2 R_{i,t} + \alpha_3 U_{i,t} + \alpha_4 H_{i,t} \tag{9}$$

where $P_{i,t}$ represents the collaborative priority of agent i at time t, $C_{i,t}$ represents its network structure position, $R_{i,t}$ represents the ability to allocate resources, $U_{i,t}$ represents the task urgency, $H_{i,t}$ represents the health risk exposure level, and α_1 to α_4 are the weight coefficients. This function combines the network location with the actual governance capacity, avoiding determining governance responsibility solely based on administrative level or agency size.

Information sharing mechanism is the basis of regional cooperative governance mechanism. Regional health risks usually have the characteristics of cross-border transmission. If the information updates are inconsistent between disease control and prevention, hospitals, communities, emergency management and grassroots service platforms,

risk identification and disposal strategies are prone to be delayed. In this paper, information sharing is designed as a data flow process of "hierarchical opening, on-demand push, trusted tracking". Public risk information can be released synchronously to the subjects in the network, while individual health information needs to be desensitized and authenticated before entering the sharing platform. The intensity of information sharing is determined by the business association between subjects, risk similarity and data timeliness:

$$S_{ij,t} = \gamma_1 L_{ij,t} + \gamma_2 V_{ij,t} + \gamma_3 T_{ij,t} \tag{10}$$

where, $S_{ij,t}$ represents the necessary degree of information sharing between subject i and subject j, $L_{ij,t}$ represents the degree of business association, $V_{ij,t}$ represents the risk similarity, $T_{ij,t}$ represents the data timeliness, and γ_1 to γ_3 are the adjustment coefficients. When $S_{ij,t}$ is high, the system can automatically increase the information push frequency and mark this relationship as a key collaboration channel.

Resource collaboration mechanism is used to solve the problem of unbalanced distribution of health resources among regions. In case of public health emergencies or rising pressure on health services for key populations, it may be difficult for a single region to independently undertake the tasks of testing, referral, material support and expert support. In this paper, medical resources, disease control resources, emergency supplies, professionals and data service capabilities are included in the unified scheduling pool, and the direction of resource flow is determined through network path selection. The amount of resource support from subject i to subject j can be expressed as follows.

$$Q_{ij,t} = \mu \cdot \frac{D_{j,t} - B_{j,t}}{K_{ij,t} + 1} \tag{11}$$

where, $Q_{ij,t}$ represents the amount of resource allocation, $D_{j,t}$ represents the health service demand in the region where subject j is located, $B_{j,t}$ represents its local available resources, $K_{ij,t}$ represents the collaboration cost between subject i and subject j, and μ represents the allocation coefficient. When the demand gap is large and the coordination cost is low, the resource flow priority increases accordingly. The design considers both regional health equity and resource scheduling efficiency.

Cross-regional coordination and disposal mechanism is the key link of governance mechanism. Information sharing and resource coordination provide the basic conditions, but the real governance effect depends on whether each subject can form a joint action around the same risk goal. In this paper, the linkage disposal is divided into five steps: risk consultation, task decomposition, action execution, process recording and result feedback. For different scenarios such as the spread of infectious diseases, continuous management of chronic diseases, public health emergencies and ecological health risks, the system generates corresponding collaborative task packages according to the risk level, and then the core nodes and bridge nodes in the network jointly promote the execution. The linkage trigger condition can be expressed as follows.

$$Z_t = \delta_1 \bar{H}_t + \delta_2 G_t + \delta_3 O_t \tag{12}$$

where, Z_t represents the regional linkage trigger value, $\bar{H}_t$ represents the regional average health risk level, G_t represents the speed of risk diffusion, O_t represents the degree of local governance overload, and δ_1 to δ_3 are the weight coefficients. When Z_t exceeds the preset threshold, the system starts the cross-regional linkage mechanism and the related subjects

enter the collaborative disposal process. In order to avoid the linkage disposal staying at the temporary response level, this paper further designs the evaluation function of the benefit of collaborative action:

$$Y_{i,t} = aE_{i,t} + bM_{i,t} + cF_{i,t} - dN_{i,t} \tag{13}$$

where, $Y_{i,t}$ represents the benefit of cooperative action of agent i, $E_{i,t}$ represents the effect of risk control, $M_{i,t}$ represents the efficiency of resource usage, $F_{i,t}$ represents the feedback of public service, $N_{i,t}$ represents the collaborative cost, and a, b, c and d are parameter coefficients. This function does not simply equate governance performance with risk reduction, but considers resource consumption and public feedback at the same time, so that regional cooperative governance can balance efficiency, equity and sustainability.

The continuous operation of governance mechanism also depends on feedback correction. After the completion of each cooperative disposal, the system records the subject response time, information sharing integrity, resource allocation arrival rate, task completion rate and public feedback results, and writes them back to the regional cooperation network. If some agents have information lag or task completion rate is low in a continuous governance cycle, the system will reduce their coordination priority. If some edge agents show strong bridging ability in practice, their network weights should be re-estimated. The mechanism update process can be expressed as follows.

$$\theta_{t+1} = \theta_t + \eta(Y_t - \bar{Y}_t) \tag{14}$$

where, θ_t represents the governance mechanism parameters, η represents the update step, Y_t represents the governance performance in this round, and $\bar{Y}_t$ represents the historical average performance. If the governance effect of this round is better than the historical level, the corresponding mechanism parameters are strengthened. If the governance effect is lower than the historical level, it is necessary to adjust the rules of information push, resource allocation or task linkage.

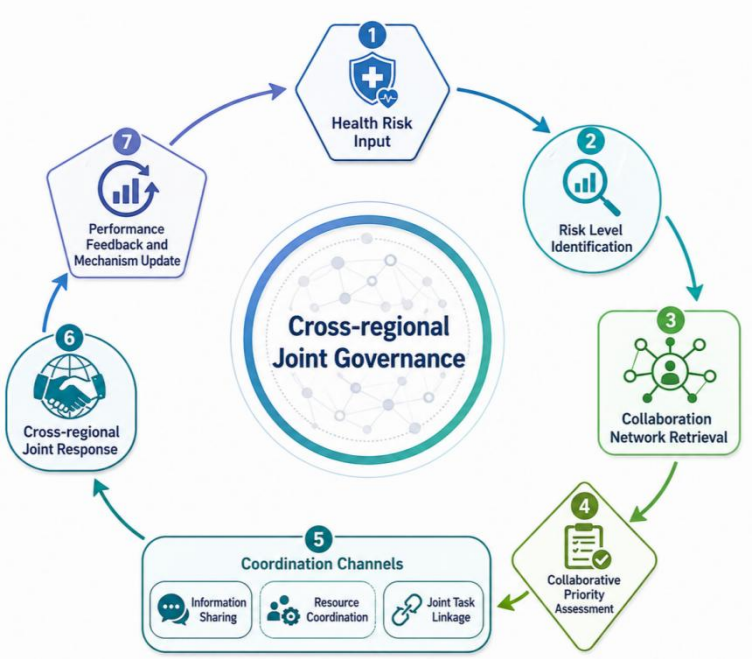

Figure 4: Closed-loop process of regional cooperative governance mechanism

The specific workflow of the regional cooperative governance mechanism is shown in Figure 4. The process starts from risk input, and passes through network analysis results calling, subject priority calculation, information sharing, resource scheduling and linkage disposal to form a closed-loop governance update. Compared with the static collaboration framework, this process emphasizes data-driven and dynamic correction, so that the regional health community can maintain strong adaptability in different risk scenarios.

From the perspective of operation mode, the regional cooperative governance mechanism designed in this paper has three characteristics. First, the mechanism is based on the analysis of real collaboration data and network structure, and can identify the key actors who actually play a role in regional health governance, rather than the division of responsibilities stuck in institutional documents. Secondly, the mechanism integrates information sharing, resource scheduling and linkage disposal into a continuous process, which can reduce information islands and repeated responses between departments. Thirdly, the mechanism introduces a computerized feedback update process, so that the cooperation network can continuously adjust with governance practices. Therefore, social network analysis is not only a description tool for regional health cooperation, but also a governance method to support the construction of human health community.

4 Practice verification and result analysis of regional health cooperation network

In order to verify the applicability of the regional cooperative governance mechanism constructed in this paper, this study took five neighboring cities in the central part of a province as case sample areas, combined with public health collaboration records and simulated governance task logs to carry out practical calculation, focusing on public health surveillance, collaborative management of chronic diseases, emergency health risk notification, linkage of medical resources and grassroots health service collaboration. Regional health collaboration records were collected from January 2023 to December 2023. The sample data sources include health department collaboration ledger, disease control and prevention agency risk notification records, medical association referral data, cross-departmental meeting minutes, emergency supplies allocation logs and primary health service platform interaction data. After the process of subject name merging, duplicate records elimination, collaborative behavior classification and relationship weight standardization, a weighted directed network with 82 governance subjects, 426 effective collaborative relationships and 5 types of subject attributes was finally formed.

The practice verification does not take a single public health event as the object, but considers the regional health cooperation process as a continuously running governance network. In this paper, Python 3.11, NetworkX 3.2, Pandas 2.1 and Gephi 0.10 are used to complete data cleaning, relationship matrix generation, network indicator calculation and visual analysis. Network nodes include health administrative departments, disease control institutions, medical institutions, grassroots service organizations and collaborative support agents. Network edges represent collaborative behaviors such as information notification, resource support, joint consultation, medical referral and risk disposal. Through this process, the collaboration status in the regional health community can be transformed into quantifiable structural indicators, which can provide data basis for the subsequent optimization of governance mechanism.

4.1 Analysis of structural characteristics of regional cooperation network

The structural characteristics of regional cooperation network are analyzed from the aspects of network scale, connection density, centrality distribution, relationship strength and cooperation differences of subject types. To facilitate the presentation of the positions of different subjects in the network, 82 nodes are divided into five categories in this paper, and the number of subjects, the number of relationships and the average weighted connection strength of each category are counted, and the results are shown in Table 2.

Table 2: Statistics of regional health cooperation network subject types and collaboration relationships

Actor Type	Number of Nodes	Number of Collaborative Relationships	Average Weighted Connection Strength	Main Collaborative Content
Health Administrative Departments	12	96	0.74	Policy consultation, resource coordination, task assignment
Disease Control Institutions	10	88	0.81	Risk monitoring, epidemic reporting, technical guidance
Medical Institutions	24	132	0.69	Referral collaboration, diagnosis and treatment support, data reporting
Grassroots Service Organizations	21	71	0.48	Follow-up visits for key populations, health promotion, demand feedback
Collaborative Support Actors	15	39	0.42	Material support, data services, social mobilization
Total	82	426	0.63	Multi-actor regional health collaboration

It can be seen from Table 2 that medical institutions have the largest number of nodes in the network and undertake more diagnosis and treatment support and referral collaboration tasks. The average weighted connection strength of CDC is the highest, indicating that it has a strong relationship viscosity in risk monitoring and information notification. Although there are a large number of grassroots service organizations, the average connection strength is only 0.48, indicating that there is still a problem of insufficient collaboration depth between them and superior departments and professional institutions. The number of relationships of collaborative support subjects is relatively small, indicating that social organizations, data platforms, and material support units are not yet fully embedded in the regional health cooperation network.

From the perspective of the overall network indicators, the density of the health cooperation network in the practice sample area was 0.128, the average path length was 2.41, the average clustering coefficient was 0.36, and the network concentration was 0.47. This indicates that a certain degree of cross-subject connection has been formed in the region, but the network still shows obvious central agglomeration characteristics. Health administrative departments and disease control and prevention institutions are in the position of information aggregation and task allocation, medical institutions have strong connection capabilities in diagnosis and treatment collaboration, and grassroots service organizations and collaborative support subjects are more in the peripheral participation state. Figure 5 further demonstrates

the average degree centrality and betweenness centrality differences for different subject types.

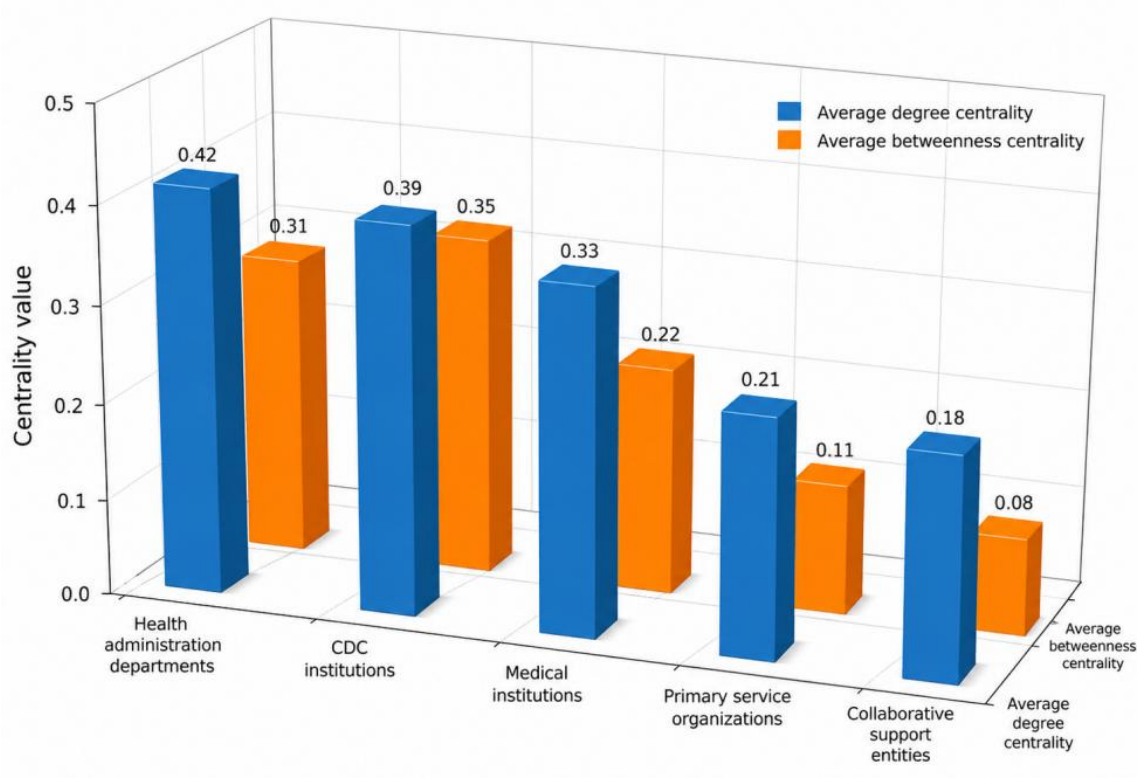

Figure 5: Comparison of centrality metrics for different subject types

It can be seen from Figure 5 that the average degree centrality of the health administration department is the highest, indicating that it has more directly connected subjects and assumes the functions of organizational coordination and task integration in regional health collaboration. The average betweenness centrality of CDCS reached 0.35, which was higher than that of other subjects, indicating that CDCS played a bridging role in health risk information transmission and inter-agency linkage. The degree centrality of medical institutions is 0.33, indicating that they have stable links with multiple governance subjects, but the intermediary centrality is lower than that of CDCS, reflecting that they are more responsible for professional service functions rather than cross-departmental coordination functions. The two types of centrality indicators of grass-roots service organizations and collaborative support subjects were low, suggesting that grass-roots demand feedback and social resource embedding are still weak links in the construction of regional health communities.

In order to further investigate the relationship distribution of the regional cooperation network, this paper counts the mean edge weight and the proportion of relationships according to the type of cooperation behavior, and the results are shown in Figure 6. The data show that the proportion of information notification relationship is the highest, reaching 34.7%. Joint consultation and medical referral accounted for 22.1% and 18.8% respectively; Resource allocation accounted for 14.6%; The collaborative support class relationship accounted for 9.8%. From the perspective of the average weight of edge, the average weight of resource allocation is 0.76, which is higher than that of other collaboration types, indicating that once resource allocation occurs, its relationship strength is high, but the frequency of this type of relationship still has room for improvement.

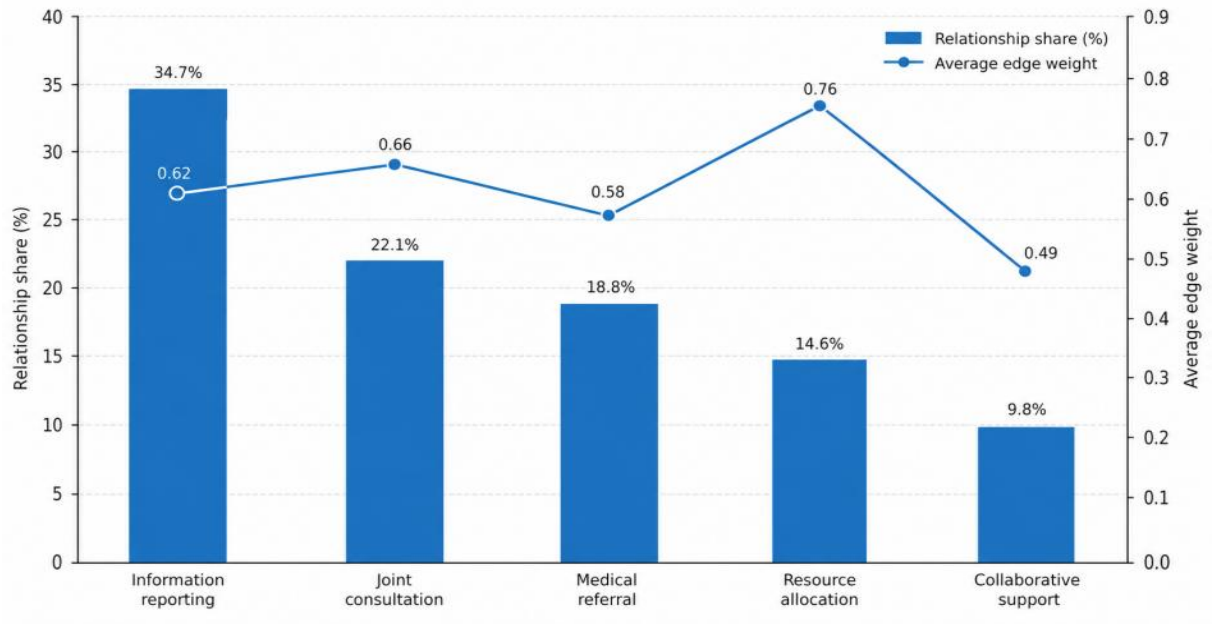

Figure 6: Distribution of collaboration types in regional health collaboration networks

Figure 6 shows that the regional cooperation network currently relies more on information dissemination and joint consultation, which belongs to the "communication-driven" collaboration structure. This structure helps to form risk cognition quickly, but it is still not sufficient in resource cross-domain allocation, grassroots service undertaking and social force collaboration. Although resource allocation has a high weight, it has not become a high-frequency cooperation behavior, indicating that the flow of materials, experts, beds and data services in health risk management has not been fully normalized. The proportion of collaborative support relationship was the lowest, indicating that the construction of regional health community still needs to expand the depth of participation of social organizations, digital platforms and third-party service institutions.

4.2 Analysis of the optimization effect of governance mechanism

On the basis of identifying the core-edge structure, collaboration type distribution and weak connection of regional health cooperation network in Section 4.1, the regional cooperative governance mechanism proposed in Section 3.2 is further embedded into the practice sample area for optimization and verification. The optimization process mainly focused on four aspects: information sharing channel reconstruction, cross-regional resource scheduling, grassroots node reinforcement and collaborative feedback update. The specific measures include: setting disease control institutions and health administrative departments as double core nodes of risk information, improving the proportion of direct connections between grass-roots service organizations and medical institutions; The resource allocation records were included into the unified scheduling platform to reduce the response delay caused by manual assignment. Part of the public health service tasks are opened to the collaborative support subjects, so that data platforms, social organizations and material support units can participate in the closed loop of risk disposal. The optimization period is from January 2024 to June 2024, and it is compared with the 2023 sample network results. In order to ensure the comparability of the results before and after optimization, this paper converts the 2023 sample data according to the monthly mean and standardized relationship strength, and uses the governance records from January to June 2024 as the optimized observation window. The structural indicators use the same node identification rules and relationship weight calculation

method, and the performance indicators use the same evaluation caliber.

To investigate the impact of governance mechanism optimization on network structure, network density, average path length, average clustering coefficient, network concentration, number of cross-city collaborative edges and number of weakly connected nodes are selected as structural evaluation indicators, and the results are shown in Table 3.

Table 3: Changes in regional health cooperation network structure before and after governance mechanism optimization

Indicator	Before Optimization	After Optimization	Change Rate	Structural Meaning
Number of Nodes	82	86	+4.9%	New data platforms and social service actors were added
Number of Collaborative Relationships	426	512	+20.2%	Effective collaborative relationships among actors increased
Network Density	0.128	0.186	+45.3%	Overall network connectivity improved
Average Path Length	2.41	2.08	-13.7%	Information and resource transmission distance shortened
Average Clustering Coefficient	0.36	0.44	+22.2%	Stability of local collaborative groups increased
Network Centralization	0.47	0.39	-17.0%	Collaboration pressure shifted from core departments to multiple actors
Number of Cross-city Collaborative Edges	117	168	+43.6%	Regional horizontal linkage was strengthened
Number of Weakly Connected Nodes	14	6	-57.1%	Embeddedness of peripheral actors improved

Table 3 shows that after the governance mechanism optimization, the number of collaborative relationships in the regional health cooperation network increased from 426 to 512, and the network density increased from 0.128 to 0.186, indicating that the interaction between regional subjects was no longer concentrated in a few administrative and professional institutions, but formed a broader horizontal connection. The average path length decreases from 2.41 to 2.08, which indicates that risk information, resource requirements and task instructions are transmitted less in the network. The network concentration decreased from 0.47 to 0.39, indicating that the problem of the original core department taking on too many coordination tasks has been alleviated to some extent. The number of weakly connected nodes is reduced from 14 to 6, reflecting that grassroots service organizations and collaborative support agents obtain more stable participation positions in the optimization mechanism.

In addition to the change of network structure, the optimization of governance mechanism also needs to be reflected in the actual collaborative performance. This paper selects indicators from five aspects of risk response, information sharing, resource scheduling, joint disposal and public service feedback for comparison, and the results are shown in Table 4.

Table 4: Comparison of collaborative governance performance before and after governance mechanism optimization

Evaluation Dimension	Indicator	Before Optimization	After Optimization	Improvement
Risk Response	Average Risk Identification Time (h)	18.6	10.4	-44.1%
Information Sharing	Key Information Completeness Rate (%)	76.5	88.2	+11.7 percentage points
Resource Allocation	Resource Arrival Rate (%)	72.8	86.5	+13.7 percentage points
Joint Response	Joint Task Completion Rate (%)	78.3	89.6	+11.3 percentage points
Grassroots Feedback	Timely Grassroots Demand Feedback Rate (%)	69.4	84.7	+15.3 percentage points
Service Outcome	Public Service Satisfaction (%)	82.1	90.4	+8.3 percentage points
Process Control	Risk Feedback Delay (h)	16.2	8.7	-46.3%

Table 4 shows that the optimized governance mechanism has obvious improvement in risk response speed and process feedback efficiency. The average risk identification time was reduced from 18.6 hours to 10.4 hours, and the risk feedback delay was reduced from 16.2 hours to 8.7 hours, which showed that the network structure optimization and digital information sharing platform had a direct effect on shortening the governance chain. The resource arrival rate increased from 72.8% to 86.5%, and the joint task completion rate increased from 78.3% to 89.6%, indicating that the resource coordination mechanism and task linkage mechanism could improve the execution quality of regional cooperation actions. The timely rate of grass-root demand feedback was increased by 15.3 percentage points, indicating that grass-root service organizations were no longer passive recipients of tasks after optimization, but were able to participate in risk identification and service feedback earlier. In order to present the optimization effect of governance mechanism more intuitively, this paper comprehensively compares the key indicators in the network structure and governance performance, and the results are shown in Figure 7.

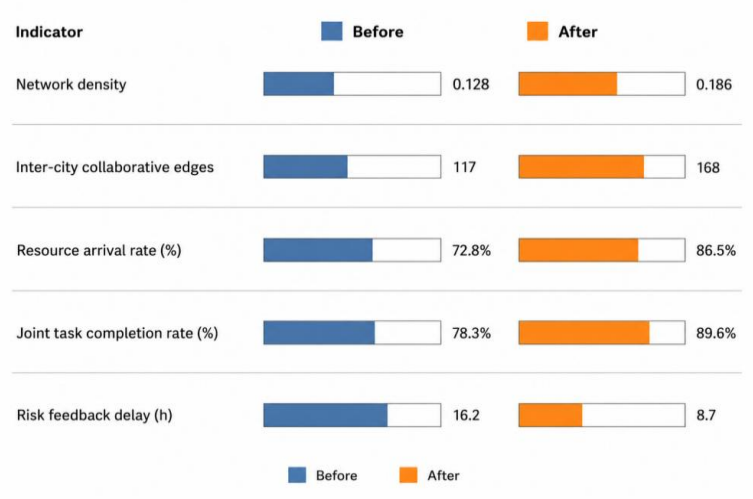

Figure 7: Comparison of regional health governance performance before and after optimization

Figure 7 shows that the governance mechanism optimization is not a single indicator improvement, but simultaneously drives changes in network connectivity, cross-city collaboration, resource scheduling, and task execution. Among them, the increase of network density and the number of cross-city collaboration edges indicated that the subjects in the regional health community were more closely connected. The increase of resource arrival rate and joint task completion rate indicates that the mechanism optimization has strong practical transformation ability. The decrease of risk feedback delay indicates that the digital collaboration platform can compress the information return time and reduce the governance cost caused by repeated confirmation and repeated submission between departments.

5 Conclusion

This paper focuses on the structure identification and mechanism optimization of regional cooperative governance in the context of human health community, introduces social network analysis method into the process of regional health collaborative governance, and constructs an analysis framework consisting of cooperative subject identification, collaborative relationship extraction, weighted network modeling, structural index measurement and governance feedback update. In this study, health administrative departments, disease control institutions, medical institutions, grass-root service organizations and collaborative support subjects are integrated into the unified network, and the behaviors such as information notification, joint consultation, medical referral, resource allocation and collaborative support are transformed into computable network relationships. The practice shows that the method can clearly present the core nodes, bridge nodes and edge nodes in regional health cooperation, and then provide data basis for the division of responsibility, resource flow and risk linkage.

In the sample area validation, after the governance mechanism optimization, the number of collaborative relationships increased from 426 to 512, the network density increased from 0.128 to 0.186, the average path length shortened from 2.41 to 2.08, and the number of cross-city collaborative edges increased from 117 to 168. At the same time, the resource arrival rate increased from 72.8% to 86.5%, the joint task completion rate increased from 78.3% to 89.6%, and the risk feedback delay decreased from 16.2 hours to 8.7 hours. The results show that social network analysis can not only describe the regional health cooperation structure, but also support the continuous adjustment of information sharing, resource coordination and linkage disposal mechanism. The governance framework proposed in this paper integrates the subject relationship, collaboration intensity and governance feedback in regional health cooperation into the same calculation chain, which provides a more operational network analysis path for the construction of human health community. Follow-up studies can further expand the regional sample scope, access real-time public health data, medical service data and grassroots health feedback data, and combine privacy computing and dynamic network prediction methods to improve the refinement and intelligence level of regional health cooperative governance.

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