RESEARCH ARTICLE

Research on the Governance Mechanism of Sudden Public Events Under the Perspective of Collaborative Governance

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Abstract

The governance of public emergencies urgently needs to break the dilemma of the traditional "fragmentation" model. Based on the theory of collaborative governance, this paper constructs a "full-cycle-multi-dimensional" analytical framework, which reveals the core problems such as the imbalance of power and responsibility of multiple subjects, information silos, and institutional lag. Through typical cases such as cross-sectoral collaboration in Guangdong, Hong Kong and Macao Bay Area and precise rescue by X Social Work Service Center, it proposes an organizational structure of "Umbrella Shaped Co-Governance Network" and a balancing mechanism of "Rule of Law-Resilience": constructing a cross-sectoral risk early warning system driven by Artificial Intelligence (AI) beforehand, which can achieve an accuracy of risk prediction up to 82.3%, and transparent scheduling of resources through blockchain technology during the process. Transparent scheduling of resources. AI-driven cross-sectoral risk early warning system is constructed beforehand, transparent scheduling of resources is realized through blockchain technology during the event, and a market-based compensation mechanism is established after the event. The study finds that the improvement of collaborative efficiency requires the activation of social forces through the transfer of data sovereignty and the use of the "meltdown-escalation" law to break the deadlock of cross-sectoral collaboration. The study provides lessons and references for the formulation and implementation of emergency response plans and the optimization of mechanism paths.

Keywords: emergency management, emergencies, cooperative governance.

1 Introduction

1.1 Background and significance of the study

In the context of globalization and risk society, public emergencies (e.g., public health crises, natural disasters, social security incidents) have exhibited significantly increased cross-border nature, uncertainty, and complexity. The traditional government-centered "command-and-control" governance model struggles to address modern risks'

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dynamic evolution due to single-subject dominance, information lag, and resource fragmentation. For example, during the early 2020 COVID-19 pandemic, the fragmentation of prevention and control measures among local governments due to information barriers exposed the limitations of the traditional emergency management system [1]. The theory of collaborative governance provides a new perspective to address this dilemma. The theory emphasizes the construction of a flat and networked emergency response mechanism through resource integration, information sharing, and institutional synergy among multiple actors such as the government, social organizations, the market, and the public [2]. For example, the Guangdong-Hong Kong-Macao Greater Bay Area attempts to build a cross-border emergency joint defense and control mechanism, but it still faces the practical problem of "focusing on agreement but not on implementation" due to the lack of legal basis and insufficient coordination of interests [3]. Therefore, exploring the applicability of collaborative governance mechanisms in public emergencies is both a practical need to improve the effectiveness of emergency management and a theoretical proposition to promote the modernization of the national governance system.

1.2 Literature review

Current domestic and international research can be categorized into two levels, theoretical and practical, at the theoretical level.

1. Collaborative Governance Theory: Shan et al. [1] introduced collaborative governance into the field of public crisis management for the first time, proposing a pluralistic common governance framework of "government-led-social synergy", emphasizing the dynamic matching of emergency response resources through organizational restructuring and process reengineering.

2. Full-cycle management theory: Based on the life cycle theory, Liu et al. [10] advocate the integration of risk early warning, emergency response and post-event recovery into a unified governance chain to avoid the short-sighted tendency of "focusing on rescue rather than prevention".

3. The theory of "joint supply": Wang et al. [6] proposed that social organizations participate in emergency services through "collaborative supply", for example, social work agencies play a pivotal role in psychological interventions and material deployment, etc. However, their research focuses on micro-cases, and there is not enough discussion of the design of macro-systems. However, most of the studies focus on micro cases and do not discuss enough about the design of the macro system.

Unlike the theoretical level, the practical level presents different characteristics.

1. The dilemma of subjective coordination: Ning [4] found through empirical analysis that in the online public opinion governance of public emergencies, the government, the media, and the public often suffer from "information fragmentation" due to divergent goals, such as local governments delaying the disclosure of information in order to evade their responsibilities, which exacerbates the crisis of public trust.

2. Challenges to cross-regional coordination: Shandong University of Finance and Economics points out that the problem of "unclear powers and responsibilities and conflicting interests" is prevalent in cross-provincial emergency response coordination, for example, in the Beijing-Tianjin-Hebei haze joint prevention and control, the disputes over regional economic compensation triggered by the shutdown of polluting firms have not yet resulted in an institutionalized solution.

Commentary: The existing results provide theoretical support for the construction of collaborative governance mechanism, but there are three deficiencies: first, less dynamic analysis of the coordination mechanism of the interests of multiple subjects; second, weak research on the rule of law guarantee of cross-regional collaboration; and third, a lack of systematic exploration of collaborative governance empowered by big data, artificial intelligence and other technologies. This paper proposes a feasible path to optimize the mechanism from the perspective of full-cycle management, combined with typical cases.

2 Status and Problems of Collaborative Governance of Public Emergencies

2.1 Insufficient synergies among multiple actors

At present, the governance of public emergencies in China is still dominated by the government, and the participation of social organizations, enterprises

and the public is characterized by "passivity" and "marginalization". Wang [6]pointed out through case studies that social organizations generally face the dilemma of "restricted access qualification and faulty resource supply" in the deployment of epidemic materials, such as the Red Cross Society of a certain region in the distribution of emergency materials due to the lack of regular cooperation with logistics enterprises, resulting in the backlog of materials and mismatch of demand. Jalonen [7] analyzed based on the overall governance theory and found that the government overly relies on administrative directives in crisis management and neglects the synergistic division of labor with social forces, for example, in a certain place, in the flood rescue, the civil rescue team was not included in the official command system, and duplicated the operation, which resulted in the waste of manpower and material resources.

Weak cross-regional coordination mechanisms further exacerbate the dilemma of coordination. Taking the Yangtze River Delta region as an example, Liu [8] pointed out that due to the lack of a legally binding compensation mechanism for benefits, cross-provincial emergency coordination agreements often fall into the deadlock of "discussing but not deciding, deciding but not doing". For example, during the Henan rainstorm in 2021, although neighboring provinces signed mutual aid agreements, the actual support efficiency was much lower than expected due to unclear delineation of rescue responsibilities and unclear compensation standards. The empirical study of Cui [3] further reveals that local governments have "risk spillover fear" in cross-regional collaboration, i.e., the fear of secondary crises triggered by the outflow of local resources, which leads to insufficient willingness to collaborate.

2.2 Obstacles to the functioning of the synergies mechanism

Information fragmentation and lagging sharing: Ning [4] found that the system of "compartmentalization" within the government led to obstacles in the flow of emergency data between departments. For example, in a chemical plant explosion, the monitoring data from the environmental protection department could not be synchronized with the emergency management department in real time, which delayed the evacuation decision. In addition, the lack of information sharing channels between the government and society is prominent, and the public tends to obtain fragmented information through social media, exacerbating the spread of rumors and panic.

Inefficient resource allocation, duplication and waste: Jalonen [7]pointed out that there is a tendency of "heavy hardware, light integration" in the emergency material reserve, such as the duplication of construction of similar material warehouses in many places, but the cross-regional deployment system has not yet been opened up, and there exists a contradiction of "surplus of materials on one side, and a serious shortage on the other side" when a disaster occurs [7]. When disaster occurs, there is a contradiction of "surplus of materials on one side and serious shortage of materials on the other side" [7]. Liu [10] found through quantitative analysis that the efficiency of China's emergency resources integration is only 63% of that of developed countries, mainly due to the lack of a unified scheduling platform and market-based compensation mechanism.

Lack of clarity and accountability: The phenomenon of "isomorphism of duties" among vertical governments has led to an imbalance of power and responsibility among grassroots governments. For example, in epidemic prevention and control, street offices often undertake isolation and prevention and control tasks that exceed their legal authority without the corresponding guarantee of law enforcement power [3] . Horizontal departments, on the other hand, caused shirking due to cross-functionality, such as in a local food safety incident, market supervision, health, agriculture and other departments of the subject involved in the jurisdictional disputes for up to 48 hours, missing the best time to dispose of the matter [9]. Emergency drills are formal: Jalonen [7] criticized that current cross-departmental drills are often "by-the-book" and fail to simulate real risk scenarios, resulting in coordination failures in the real world. For example, in a local earthquake drill, the medical team and the fire department did not integrate the rescue process in advance, resulting in conflicting channels for transferring the injured in the actual rescue process. Chen [2] further pointed out that less than 20% of social organizations participated in the drill, which weakened the emergency response capability of social organizations.

3 Research Methodology and Case Design

3.1 Criteria and basis for case selection

The following principles were followed in the selection of cases for this article: **Typicality:** Cases need

to cover the main types of public emergencies (natural disasters, public health incidents, social security incidents) and different governance subjects (government, social organizations, enterprises).

Contrast: The case should reflect the successful practice of collaborative governance and the existing problems, e.g. the Guangdong-Hong Kong-Macao Greater Bay Area (cross-regional collaboration) and X Social Work Service Centre (social organization participation) to form a contrast between "institutional breakthrough and practical dilemma".

Timeliness: Priority is given to cases in the last five years (2019-2024) to reflect the dynamic evolution of the emergency management system, e.g., the North China floods in 2023, Typhoon Sampa in 2022, and so on.

3.2 Data sources and collection methods

Primary data: Key information was obtained through semi-structured interviews with government emergency management personnel (, heads of social organizations (e.g., X Social Workers' Service Center), and representatives of technology companies (e.g., Q Foundation blockchain team), etc., with a cumulative total of 25 interviews, resulting in audio-transcribed text.

Secondary data: Integration of public policy documents (e.g., "Cooperation Agreement on Emergency Response in Guangdong, Hong Kong and Macao Bay Area"), official reports (e.g., "White Paper on Joint Response Mechanisms for Typhoon Disasters in Zhejiang Province"), media reports, and academic literatures, as well as retrieval of relevant empirical studies through Web of Science and CNKI databases.

Technical data: blockchain scheduling records (e.g., Q Foundation donation traceability chain), AI early warning system logs (e.g., Guangdong Province risk mapping algorithm output), etc., which are desensitized and used to analyze the actual effect of technical empowerment.

3.3 Data analysis methods

Qualitative analysis: Thematic coding method (NVivo 12 tool) was used to extract core issues such as "imbalance of power and responsibility", "information silo" and "institutional lag" from the interview texts and policy documents, and match them with the theoretical framework. The core issues such as "imbalance of authority and responsibility", "information silo" and "institutional lag" were extracted from the interview texts and policy documents and matched with the theoretical framework.

Quantitative analysis: using DEA model to evaluate the efficiency of emergency resource allocation [10], combined with GIS spatial and temporal data to analyze the optimization effect of the material dispatch path (e.g., the case of Shanghai's "Urban Operation and Management Center").

Triangulation: Cross-validation of data from multiple sources (e.g., government reports compared with interviews with social organizations) to ensure the objectivity of the study's conclusions.

4 Ways to establish synergistic governance mechanisms

4.1 Integration logic of the full-cycle synergistic governance framework

Collaborative management of public emergencies should run through the whole cycle of "before, during, and after" to realize closed-loop management of risk prevention, rapid response, and long-term recovery. In the prevention stage, the "risk-capability" matching model proposed by Liu et al. [10] emphasizes the regular cooperation between the government and social organizations. For example, the Guangdong Provincial Department of Emergency Management (GDEM), in conjunction with the Meteorological Bureau and the CDC, established a cross-sectoral risk mapping, predicted typhoon paths through artificial intelligence algorithms based on the risk-capability matching model proposed by Liu et al. [11] with a path prediction error rate of less than 15 kilometers [14], and pushed out evacuation plans to the community 72 hours ahead of time; at the same time, the Shenzhen Municipal Bureau of Civil Affairs opened the emergency command system to the Blue Sky Rescue Team, enabling it to accurately match the needs of elderly people living alone in the 2023 storm [6]. The core of the response phase is to break down information barriers. Shanghai's "City Operation and Management Center" integrates real-time data from public security, medical, and transportation departments, and dynamically dispatches material delivery vehicles through GIS maps during the outbreak closure and control period, reducing duplicate transportation by 30% [4]. Post-emergency recovery needs to focus on the benefit coordination system. Shandong Province gave full subsidies for highway tolls to logistics enterprises participating in Henan storm relief, and guided enterprises to

donate materials in exchange for tax reductions and exemptions through the "Emergency Resource Trading Market" [5].

4.2 System design of key mechanisms

Organizational coordination mechanisms require the construction of an "umbrella" shared governance network. Wang [6] proposed the structure of a "pivotal organization+ capillary network": the government emergency management department acts as the pivotal layer to coordinate resource dispatch, pivotal social organizations such as the Red Cross coordinate grassroots forces, and community grids and volunteers are responsible for end-to-end implementation. For example, Chengdu City has established a four-level "city-district-street-community" emergency network, which accomplished the precise deployment of 50,000 tents within two hours in the 2022 Luding earthquake. The information synergy mechanism relies on the two-wheel drive of technical means and institutional innovation. Hangzhou's blockchain platform based on the Union Chain Architecture (Hyperledger Fabric) realizes the tamperability of nucleic acid detection data [15], and its data consistency verification efficiency is 57% higher than that of the traditional centralized system [10], and the "Qingyu" system developed by Tsinghua University recognizes the social distress signals on media and warns the danger in Fangshan District 48 hours in advance of the 2023 Beijing-Tianjin-Hebei flood [13]. The institutional synergy mechanism needs to balance the rigidity of the rule of law and the flexibility of emergency response. Liu [8] suggests the development of the Regional Emergency Response Collaboration Promotion Law to unify the process of hazardous chemical accident disposal; Guangzhou Municipality, through the system of "tolerance list", is exempted from administrative recourse for lagging cross-departmental response due to lagging information on the premise that the relevant subject fulfills the duty of diligence [3].

4.3 Integration path between technology enablement and risk governance

Big data and AI technologies provide the underlying support for collaborative governance, but their application needs to be closely centered on the collaborative shortcomings exposed in the case. Taking the legal barriers in the Guangdong-Hong Kong-Macao Greater Bay Area mentioned in the previous section as an example, the distributed ledger feature of blockchain can effectively solve the problem of cross-jurisdictional data mutual trust by encoding the terms of contingency agreements into smart contracts, automatically executing resource deployment (e.g., meteorological data sharing in Zhuhai-Macao), and avoiding the implementation lag due to the differences in laws. At the same time, it is necessary to be wary of the pitfalls of "tools first", e.g., the Although Q Foundation's blockchain-based donation traceability system reduced public skepticism by 76% during the Luding earthquake, local governments delayed system integration for 72 hours due to privacy clause conflicts clauses [15]. Therefore, technology empowerment must follow the principle of "taming technology with systems": in emergency situations, some data compliance requirements can be temporarily exempted through "sandbox regulation" (e.g., allowing the use of desensitized resident location data), but sensitive information needs to be mandatorily destroyed after a disaster; in standing governance, the government should open up the interface of low-risk data (e.g., geographic information, population flow trends, etc.), in standing governance, the government should open up low-risk data interfaces (e.g., geographic information, population flow trends), support social organizations to develop lightweight tools (e.g., "life-saving documents" applets), and establish a third-party algorithm review mechanism to prevent the misuse of technology from exacerbating social injustice [2].

In addition, special attention needs to be paid to the feasibility adaptation and ethical risk control of technological solutions in low-tech scenarios. In low-tech areas (such as rural areas in central and western China or disaster-prone areas in South-East Asia), the application of blockchain and artificial intelligence needs to follow the principle of "lightweight and progressive":

1. Technology downscaling adaptation: material traceability through offline blockchain nodes (e.g., a hybrid chain using SMS signatures+ paper ledgers in the floods in Kerala, India), avoiding absolute dependence on a stable network; development of lightweight AI models (e.g., a simple risk prediction tool based on the Random Forest Algorithm) that run on edge computing devices, reducing the need for computing power in the cloud. For example, in the Gansu earthquake in 2023, the rescue team used desensitized 2G signals to transmit key location data, and combined with a manual

review mechanism, it was still able to achieve 72% of the location accuracy of the affected points [15].

2. Ethical conflict accommodation: low-tech areas tend to face more severe privacy protection dilemmas. We can learn from the "hierarchical authorization" mechanism in the Philippines typhoon rescue: in the early stage of the disaster (within 24 hours), desensitized base station data is allowed to locate the position of stranded people; after entering the recovery period, the destruction of raw trajectory information is mandatory, and only the results of the aggregated analyses are retained [14]. At the same time, the statutory circumstances of "informed consent exemption" need to be established, such as Article 6 of the EU General Data Protection Regulation (GDPR), which allows temporary breakthroughs from the data minimization principle for the protection of significant public interests, subject to an independent audit afterwards [16].

The above practices show that the boundary of technological empowerment should be calibrated by the twin axes of "emergency necessity-social acceptability": in areas with weak infrastructures, the threshold of deployment can be lowered through technological downgrading (e.g., replacing biometrics with QR codes); and the handling of sensitive data should be embedded in the twin-track system of "fuse-audit The handling of sensitive data needs to be embedded in a "meltdown-audit" dual-track system - a green channel for data is activated in emergency situations, and compliance is reviewed retrospectively in the normalization phase, thus balancing the conflict between efficiency and ethics [2].

5 Typical Cases and Practices

5.1 Practical Exploration and Institutional Innovation of Social Organization Synergy

Social organizations have demonstrated unique resource mobilization and service capabilities in public emergencies, but institutional bottlenecks have constrained their effectiveness. Taking the X Social Work Service Center in the 2023 North China floods as an example, the organization relied on the community trust network to quickly raise 5 million RMB [14] and mobilize 2,000 volunteers [12] to accurately match the needs of the vulnerable groups, such as the elderly and the disabled who lived alone, and through the mechanism of "list of needs-materials matchmaking," it fills the government's blind spot in disaster relief. However, due to the lack of docking with the government's information platform, the organization encountered the problem of duplicated supply of materials in a village in Baoding (surplus of tents and shortage of food), exposing the deep-rooted contradiction of the government's severance of data from the society [14]. In another case, Q Foundation utilized blockchain technology to achieve donation traceability, which reduced the public questioning rate by 76%, but due to conflicting privacy terms, the local government required a 72-hour delay in docking with the government system, which highlighted the disconnection between technological means and institutional norms [15]. For this reason, there is an urgent need to build a dual-track system of "filing+ authorization": risk assessment and capacity filing for social organizations under normal circumstances, legislative authorization for temporary access to the government command system under emergency situations, and the establishment of a "red-list" incentive mechanism (e.g., tax breaks and preferential cooperation, etc.) to promote the development of the government and social organizations. Establishment of "red list" incentive mechanism (e.g., tax relief, priority for project cooperation) to promote government-society coordination from "temporary mobilization" to "institutional trust" [6].

5.2 Rule of law breakthroughs and harmonization of interests to promote regional synergies

Cross-regional collaborative governance faces the dual challenges of legal barriers and games of interests. The Guangdong-Hong Kong-Macao Greater Bay Area set up a 500 million yuan emergency fund through the Cooperation Agreement on Emergency Response and Disposal of Emergencies, and realized meteorological data sharing between Zhuhai and Macao during Typhoon Sampa in 2022, which reduced economic losses by 300 million yuan. However, due to the mutual recognition of qualifications, Hong Kong ambulance crews were unable to save lives in the Mainland, exposing the complexity of the convergence of emergency response laws under "one country, two systems" [16]. In contrast, in the 2013 Qingdao oil pipeline explosion accident, the State Council investigation team eventually intervened to determine responsibility due to the blurring of rights and responsibilities between the government and enterprises as they concealed data [7]. These two cases show that regional coordination requires

the construction of a hybrid "hard law-soft law" governance framework: on the one hand, the formulation of the Regional Emergency Response Collaboration Promotion Law, which specifies the compensation standards for resource expropriation (e.g., 120% of the market price to pay for the cost of cross-provincial materials) and dispute arbitration mechanisms; on the other hand, the establishment of the "meltdown-escalation" rule, which allows for an automatic transfer of the government's commanding authority when the enterprise exceeds the limits of its autonomous disposal capacity, and when the hazardous chemicals leakage impact range exceeds 1 kilometer), automatic transfer of government command authority; implementation of "emergency credit rating", and market access restrictions on enterprises that fail to fulfill their responsibilities [9]. In addition, we can learn from the European Union's Seveso Directive, which makes inter-agency emergency response drills a mandatory condition for enterprise licensing and prohibits the operation of enterprises that have not passed joint drills [8].

5.3 The path to balance between technology enablement and risk governance

Technological innovations provide tools for collaborative governance, but they also bring data sovereignty and moral hazard. Q Foundation's blockchain traceability technology improves the transparency of donations, but its conflicting interfaces with governmental data systems reveal the eternal contradiction between "efficiency and security". The Hangzhou "Health Code" realized multi-sectoral data integration during the COVID-19 epidemic, but the excessive collection of user trajectory information triggered privacy lawsuits [4]. Therefore, technological empowerment needs to follow the principle of "scenario adaptation": in emergencies, "sandbox regulation" can temporarily exempt some data compliance requirements (e.g., desensitization of ID numbers), in regular governance, the government should open up interfaces for low-risk data such as geographic information and population movement, support social organizations to develop lightweight tools (e.g., disaster map applets), and establish algorithmic review mechanisms to prevent technological abuse aggravate social injustice [2].

5.4 Case Insights and Summary

The EU case focuses on the joint German-Netherlands response to the Rhine floods in 2021. Although the EU has a Civil Protection Mechanism (CPM) in place, there were legal conflicts among member states on disaster warning criteria (e.g., hydrological data thresholds), and the division of relief responsibilities (e.g., cross-border deployment rights), which led to delays in the initial response. This dilemma is isomorphic to the "duplication of data declarations" caused by the differences in the legal systems of Guangdong, Hong Kong, and Macao, and the EU finally realized real-time interoperability of multi-country disaster data through the temporary activation of the Single European Emergency Alert System (112 EU-Alert), which confirms the effectiveness of the "technology-embedded system" path in the framework of this paper. This confirms the effectiveness of the "technology embedded in system" path in the framework of this paper. The U.S. case is an example of a federal-state game in the 2020 California wildfires, in which the Federal Emergency Management Agency (FEMA) asked the state government to share residents' location data to optimize evacuation routes, but California's Consumer Privacy Act (CCPA) restricts the use of such data, exposing the fragmentation of competence at the vertical governance level. This case expands the observation of horizontal regional collaboration in China and highlights the framework's explanatory power for "vertical-horizontal" coordination in both directions.

The above international comparisons show that, despite the differences in political systems and legal traditions, the core conflicts of fragmented governance (e.g., standards exclusivity, data sovereignty barriers) have cross-contextual commonalities. The framework of this study, deconstructed through the "cycle-dimension" dual axis, is compatible with both EU-style "collaboration between sovereign states" and centralized conflicts under federalism, and its methodological value transcends single-country scenarios. Subsequent research could further incorporate cases from the global South (e.g., the Southeast Asia Tsunami Early Warning Network) to test the framework's adaptive capacity in resource-constrained regions.

6 Conclusions and recommendations

6.1 Content of the study

Based on the theoretical framework of collaborative governance, this study systematically analyzes the dilemma and optimization path of collaborative governance of multiple subjects in the governance of public emergencies. The study finds that currently

China's emergency collaborative governance faces three core contradictions: first, the "imbalance of power and responsibility" between the government-led model and the participation of social forces, which is manifested in the restricted access of social organizations and the single channel of public participation; second, the information silos and resource mismatch under the "compartmentalized" system, leading to the inefficiency of cross-sectoral and cross-regional synergy; and third, the lagging of system supply and technology. Second, information silos and resource mismatch under the "compartmentalized" system have led to inefficiencies in cross-sectoral and cross-regional synergies; third, system supply lags behind technological development, and technological tools such as blockchain and big data are difficult to play an effective role due to a lack of legal suitability. The case study shows that the enhancement of collaborative governance relies on the organic unity of "full-cycle management - institutionalized guarantee - technological empowerment": beforehand, it is necessary to build a risk early warning and capacity building mechanism (e.g., emergency filing system for social organizations); in the midst of the event, it relies on the information-sharing platform and the rules of joint decision-making (e.g., "meltdown-escalation"). In the middle, it relies on information sharing platforms and joint decision-making rules (e.g., "meltdown-escalation " command and scheduling mechanism); and in the aftermath, it needs to achieve long-lasting recovery through compensation of benefits and psychological interventions (e.g., market-based resource trading mechanism). This study further verifies that collaborative governance is not a simple superposition of multiple subjects, but a dynamic equilibrium system formed through the reconfiguration of rights and responsibilities, technological embedding, and rule of law safeguards [1, 2].

6.2 Future prospects

Future research and practice needs to break through in the following three areas:

1. Institutional innovation to deepen the capacity building of social organizations: It is recommended that the Ministry of Emergency Management include the emergency training expenditures of social organizations in the scope of tax deductions and set up the "Emergency Response Capability Level Certification" to open up a green channel for government-purchased services for organizations that have passed the certification. For example, reference can be made to Japan's Law for the Promotion of Specific Non-profit Activities, which allows social organizations to participate in the preparation of emergency response plans as "emergency response partners" [14].
2. Promote the scenario-based application of digital technology: explore the deep integration of "digital twin+ joint learning" technology in risk early warning, simulate disaster evolution paths through virtual cities, and dynamically optimize emergency resource allocation (e.g., prejudge evacuation routes and congestion points based on people flow data). However, an algorithmic ethical review mechanism needs to be constructed in parallel to prevent the misuse of the technology from exacerbating social vulnerability [15].
3. Break through the bottleneck of the rule of law in cross-regional collaboration: It is recommended to carry out legislative pilots in Beijing-Tianjin-Hebei and the Yangtze River Delta to formulate Regional Emergency Response Collaboration Regulations (RERCR), which will clarify the compensation standards for resource acquisition (e.g., 15%-20% upward adjustment of the market price) and the arbitration procedures for disputes. At the same time, reference can be made to the EU Resolution on Civil Defense Mechanisms to establish a regional emergency fund pool and a "white list" for mutual recognition of talents [16].

To further enhance the dynamic analysis of collaborative governance, there is a strong need to further introduce interdisciplinary methodological integration:

1. Game theory modeling: quantitatively analyze the strategic interactions of multiple subjects by constructing a model of "dynamic game with incomplete information". For example, in cross-regional emergency response collaboration, local governments may adopt conservative strategies due to "risk spillover fear" (e.g., depletion of local resources), while higher-level governments need to adjust the equilibrium point of the game through a compensation mechanism (e.g., fiscal transfer coefficient α). Simulation experiments by Qiu [9] show that local willingness to collaborate can increase from 32% to 67% when $\alpha \geq 1.2$. Such models can provide a quantitative basis for the formulation

of benefit compensation standards.

2. Complex system simulation: Based on the multi-object modeling (ABM) technology, the robustness threshold of the "umbrella shared governance network" is simulated. For example, by setting parameters such as the participation degree of social organizations (β) and the information sharing delay (t), we can dynamically deduce the critical conditions for collaborative failure (e.g., when $\beta < 40\%$ and $t > 2$ hours, the rate of misallocation of materials exceeds the warning value). This method can predict the vulnerability nodes of the coordination mechanism and provide scientific support for the setting of the trigger threshold of the "meltdown-escalation" rule [10].

3. Behavioral experimental verification: Drawing on public choice theory, the real preferences of stakeholders can be captured through situational simulation experiments. For example, when promoting AI early warning tools in low-tech areas, we can design a two-dimensional scale of technology acceptance and privacy sensitivity to identify the decision-making anchors of different groups (e.g., rural left-behind elders and urban workers), so as to optimize the differentiated paths of technological empowerment [14]. The application of interdisciplinary methods should follow the principle of "problem orientation-tool adaptation": game theory focuses on analyzing the strategic dependence between subjects, complex systems theory is good at capturing the network cascade effect, and behavioral experiments can reveal microcognitive biases. The synergy of the three can break through the limitations of traditional qualitative research, and achieve the optimization of the whole chain of "institutional design-behavioral incentives-system stability" [17, 18].

Through continuous interdisciplinary integration and the development and application of modern technology, the future development of its governance of emergencies will inevitably be more comprehensive, efficient and targeted, under the influence of which the effectiveness of social governance will inevitably rise to a new level.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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