

Unlocking data elements potential for enhanced urban public health emergency governance: Configuration analysis based on 23 mega-cities in China

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Abstract: As the core production element of the digital era, data's multiplier effect is key to risk prevention and the modernization of emergency governance. This article combines the practical application of data elements in public health emergency management, based on the technology-organization-environment (TOE) theoretical framework, takes 23 mega-cities in China as research cases, and uses the fuzzy-set qualitative comparative analysis (fsQCA) method to explore the impact of technology, organization, environment, and other conditions on the effectiveness of urban public health emergency governance. The results show a significant conditional correlation between the effectiveness of urban public health emergency governance and the conditions for applying data elements. Based on the characteristics of multiple concurrent paths, the driving paths can be classified into three categories: "technology-based", "organization-environment dual core", and "organization-technology as the mainstay + environment as the supplement". Local governments should combine the regional digital resource endowment, promote phased and differentiated application of data elements, strengthen interconnection of data-sharing platforms, coordinate construction of institutional mechanisms, accelerate multi-scenario application of data elements, strengthen two-way empowerment of technology-driven and organizational coordination, and effectively transform linkage advantages of multidimensional elements into governance effectiveness.

Keywords: data elements, emergency management, public health, mega-cities, configuration analysis

1. Introduction

As China's modernization advances, the connotation and extension of people's demand for security are more abundant. Effectively preventing and resolving sudden public health risks bears directly on national development and security, as well as overall social and political stability. Both the 15th Five-Year Plan and the Fourth Plenary Session of the 20th Central Committee of the Communist Party of China emphasized the need to strengthen the public health system, elevate public safety governance standards, and enhance effectiveness of coordinated emergency response and disease prevention and control. Cities, as hubs where diverse elements and economic activities converge most intensively, also serve as primary arenas bearing the brunt of disaster risks. In a realistic situation where the governance of risk complexity does not match the strip governance model, fragmentation of urban emergency governance functions further constrains governance efficiency. In

recent years, rapid expansion of the digital economy has catalyzed an unprecedented transformation: human, spatial, material, and event-related elements in urban areas are progressively being digitized, fundamentally reshaping governance paradigms. Data resources, however, only unlock their full potential when applied to specific domains. As a new production factor, data can embed itself within traditional elements in informational form, generating multiplicative value through integration, amplification, and synergistic effects. Recognizing this, "Three-Year Action Plan for 'Data Element×'(2024–2026)" explicitly identifies "data element×emergency management" and "data element×urban governance" as core priorities, proposing to enhance emergency coordination and data-sharing capabilities, promote the integration of multi-dimensional urban data, and support the application of data elements in public health, public safety, and other fields.

Existing research mainly explains the enabling mechanism of big data technology in public health

governance from the aspects of monitoring and early warning, prevention and control strategies, and integrated risk management. Scholars argue that big data can break the information monopoly, promote comprehensive risk governance, and reshape the risk governance process (1-4). However, data is not a panacea—its introduction does not automatically eliminate deficiencies in existing emergency response systems and mechanisms (5). In practice, big data may fall short of expectations in governing urban public health emergencies. If used improperly or insufficiently, unexpected difficulties may be encountered (6). Moreover, the anticipated improvements in quality and efficiency from data element applications largely rest on theoretical deductions of technical logic. A potential mismatch between technical logic and actual organizational dynamics may hinder integration of big data technology and limit its effectiveness in public health emergency governance (7). So, what factors influence application of data elements in urban public health emergency governance? What configurational relationships exist among these factors, and how can they be leveraged to enhance governance effectiveness?

To address these questions, this article examines public health emergencies as a case study, selecting actual cases from 23 mega-cities in China, and uses the fuzzy-set qualitative comparative analysis (fsQCA) method to conduct configuration analysis. The marginal contribution of this article is that utilization of the fsQCA method to confirm multiple non-exclusive configuration paths for public health emergency governance effectiveness. This is conducive to deepening understanding of the mechanism of action in public health emergency governance, and promoting comprehensive modernization of digitally-enabled emergency governance.

2. Theoretical Analysis Framework

Government emergency governance aims to respond to sudden crises quickly and effectively, thereby minimizing casualties and property losses (8) and eliminating risks or potential risks in human activities (9). As a new type of production element, data can attach itself to traditional elements in information form, enhancing total factor productivity and generating multiplicative value through integration, amplification, and synergistic effects. Therefore, data elements can provide new technical support and strategic resources for urban public health emergency governance, reshape system architecture, and promote an intelligent emergency governance model (10).

Existing research has explored data elements' application process and role in public health emergency governance, preliminarily establishing a fuzzy correlation between data elements and governance effectiveness (11,12). However, few studies have explained the differentiated pathways to achieving effective

governance. There is a lack of exploratory empirical analysis of combined linkage effects among various elements. In the digital age, all information elements, such as people, places, objects, events, and organizations, are highly correlated. The various elements within data-driven public health emergency governance processes are interdependent, and action paths for emergency governance effectiveness are also different. The key to effective governance lies in embedding big data throughout the entire emergency governance process, insuring accurate selection and design of data technology, and realizing the two-way empowerment of data elements and risk factors in the reconstruction of the entire process. Therefore, we attempt to introduce the fsQCA method and, based on the analysis ideas of the technology-organization-environment (TOE) framework proposed by Tornatzky and Fleischer (13), construct a theoretical explanatory framework for data elements to empower urban public health emergency governance effectiveness (Figure 1).

First, technical conditions. Specifically, two secondary conditions are introducing new technologies and establishing a data-sharing platform. Modernizing public health emergency governance systems and capabilities is inseparable from modern information technologies such as the Internet, big data, and cloud computing (14). By adopting new technical methods, a large amount of data can be analyzed and interpreted, breaking down "data barriers" and "data chimneys" (15), enabling information resource sharing and coordinated action within emergency systems (16), and improving risk perception and response capabilities. At the same time, with the advent of the risk society, risk factors in the public health field have increased significantly, and data openness and sharing also face various security risks. In response to major epidemic crises, building a data open-sharing and reuse platform based on emerging technologies such as privacy computing, secure multi-party computing, federated computing, and blockchain, can break down information islands across government departments. This not only provides data support for preventing viral spread, but also furnishes evidence sources for "evidence-based decision-making", thereby achieving sustainable long-term development of public health emergency governance.

Second, organizational conditions. Specifically, two secondary conditions exist: organizational system guarantee and government attention allocation. From the evolution of China's emergency management system, the focus of emergency management coordination has expanded from information and public opinion to plans, teams, and equipment and from emergency response to the entire prevention, preparation, response, and recovery process (17). It has gradually formed a strong institutional advantage and has become a prerequisite for effective coordination among all parties. Based on Simon's bounded rationality decision-making theory,

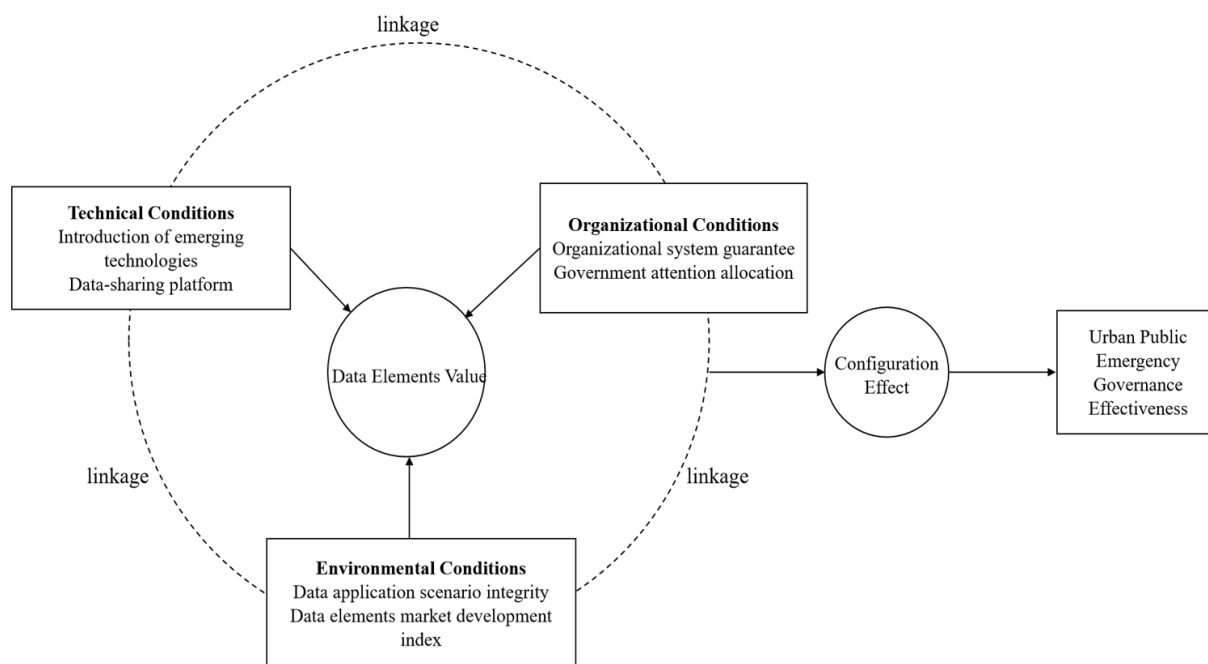


Figure 1. Theoretical analysis framework.

government attention is a scarce resource, and local decision-makers' behavioral choices depend on which issues and solutions they prioritize. Under conditions of agenda overload and limited governance resources, scarce government attention becomes key to effectively utilizing various data resources (18). In other words, when government decision-making agencies pay more attention to or prioritize data elements and their governance, this directly affects the realization process of data elements empowering public health emergency governance.

Third, environmental conditions. Specifically, they include two secondary conditions: data application scenario integrity and data elements market development index. Data only maximizes its value through application, and its value can only be fully explored when placed in specific application contexts. Based on the "risk governance chain" (19), big data applications in public health emergency governance are primarily reflected in multi-stage scenarios such as risk monitoring, risk warning, and risk response. The integrity of its application scenarios will affect release of the value multiplier effect of data elements. As the leading force in emergency management, the digital environment prompts the government to accelerate development and utilization of data resources and smooth the environment for data sharing and cooperation among departments. In 2020, the "Opinions on Further Improving the System and Mechanism of Element Market Allocation" proposed accelerating cultivation of the data elements market. Properly understanding and grasping the value creation mechanism of data elements enables optimal allocation of data across different stages of factorization through market-oriented means, thereby fully leveraging the role

of data element markets in promoting digital construction of local governments.

3. Materials and Methods

3.1. Selection of research cases

QCA is a case-oriented research method, and selecting research cases is essential to applying this method. In our research, Mega-cities, serve as primary carriers of disaster risk shocks, given their complexity and dynamic nature. When public health incidents occur in large cities, transmission speed, control difficulty, and harm severity far exceed those in other areas. The public health security situation is more difficult, and urban emergency governance capabilities directly impact local public health services and risk control. To deeply explore which factors may drive or constrain application of data elements in urban public health emergency governance, this study is rooted in China's public health response practices and combined with the National Urban Construction Statistical Yearbook data to collect and organize the required research cases comprehensively. Among them, there are 8 super large-sized cities, including Shanghai, Beijing, Shenzhen, Chongqing, Guangzhou, Chengdu, Tianjin, and Wuhan, and 15 very large-sized cities, including Hangzhou, Dongguan, Xi'an, Zhengzhou, Nanjing, Jinan, Hefei, Shenyang, Qingdao, Changsha, Harbin, Kunming, and Shijiazhuang. Thus, a preliminary sample of 23 mega-cities was obtained, and case materials for each sample city were further collected. The selected case cities usually cover multiple regions, such as Central China, South China, North China, West China, and East China, and resource

endowments, crisis response measures, and effectiveness of each region are different. Overall, they conform to the principles of "maximum similarity" and "maximum difference", ensuring the scientific and accuracy of the research process.

3.2. Variable measurement and calibration

3.2.1. Outcome variable

We focus on the effectiveness of urban public health emergency governance. Government emergency governance aims to quickly respond to emergencies, thereby minimizing casualties and property damage to the greatest extent possible (20). "The Emergency Response Law of the People's Republic of China", "The National Emergency Plan for Public Health Emergencies", and other laws and regulations all emphasize the need to effectively prevent, control, and eliminate the hazards of public health emergencies, protect physical health and safety of the public, and maintain regular social order. Referring to the performance measurement standards of government public health governance of Tao *et al.* (21), combined with the complexity of risk prevention and control in mega-cities, three indicators were used to measure the urban public health emergency governance effectiveness: "the proportion of urban elderly in the total population at end of the year", "birth rate in various regions", and "incidence rate of Class A and B infectious diseases". These indicators are used as macro-level proxy measures reflecting long-term risk control capacity rather than short-term response performance, capturing the aggregate outcomes of public health emergency governance under sustained stress. Relevant data mainly come from the economic and social development bulletins and health development statistics bulletins issued by the Local Bureau of Statistics, Health Commission, and Centers for Disease Control and Prevention. Among them, the proportion of urban elderly in the total population at the end of the year and the birth rate in various regions will be based on the latest data released in 2024, while the incidence rate of Class A and B infectious diseases will be obtained by taking the average value from 2019 to 2023 to reflect the impact of the global epidemic crisis accurately.

3.2.2. Antecedent conditions

First, technical conditions. Introduction of new technologies is measured by the number of emerging technologies and methods, such as big data, cloud computing, blockchain, artificial intelligence, 5G, and the Internet of Things used in epidemic monitoring and analysis, virus tracking, prevention and control, and resource allocation. The data-sharing platform provides information support for public health risk assessment and coordinated response. By examining the number of public

data-sharing platforms established by local governments, we can understand integration of data elements and public health risk response. Second, organizational conditions. Organizational system assurance is measured by the number of data governance policies issued by local governments. Specifically, we use keywords such as "data", "numbers", "data elements", and "digital technology" to collect and tally relevant policy texts. In December 2022, the Central Committee of the Communist Party of China and the State Council issued the "Opinions on Establishing a Data Infrastructure System to Better Leverage the Role of Data Elements" (referred to as "Data 20"), which is the first national remarkable policy document to systematically deploy value release of data elements from the perspective of production elements. Subsequently, Beijing, Shanghai, Shenzhen and other places successively issued a series of data element related policy documents. This article measures the government's attention allocation by the time difference between releasing "Data Element" policies and "Data 20" in sample cities. Third, environmental conditions. The integrity of data application scenarios is measured based on the number of big data applications in areas such as community prevention and control, emergency coordination, post-disaster recovery, resumption of work and production, *etc.*, reflecting the scope of data application scenarios. The data elements market development index focuses on four dimensions: the development foundation of data elements, data governance and security, data elements supply, and data elements circulation. We combine the relevant indicator data from "China Urban Data Elements Development Index (2024)" and "China Digital Economy Development Index Report (2024)" for comprehensive measurement.

3.2.3. Variable calibration

In fsQCA, each condition and outcome is treated as an independent set, and each case has a membership score in these sets. The original cases must go through a calibration process. The data are converted into a fuzzy set of membership numbers. QCA calibration methods include direct and indirect methods. The results and conditional variables involved in this article lack empirical knowledge as a calibration basis. Therefore, following mainstream QCA research, objective quantile values are used to determine qualitative anchor points to reduce subjective bias and bias caused by outcome orientation. Specifically, 95%, 25%, and 5% of the sample data are used as the anchor points of the "completely affiliated", the "intersection point" and the "completely non-affiliated" attributes, respectively. Reasonable adjustments are made according to the actual situation (Table 1).

4. Configuration Analysis Results

4.1. Necessity analysis of a single condition

Before analyzing the sufficiency of condition type configuration, it is necessary to conduct necessity analysis for individual conditions individually to determine whether there is a specific condition that constitutes the necessary conditions of the resulting variable. Therefore, in this study, we adopt fsQCA version 3.0 to analyze the consistency and coverage of each condition variable. Table 2 shows the necessity analysis of a single condition. The results show that the consistency levels for all conditions are lower than 0.9. Therefore, a single condition variable cannot constitute a necessary condition for the result. It is necessary to further explore the combined linkage effect of the three dimensions of technology, organization, and environment throughout the application process of data elements.

4.2. Sufficient condition analysis

Concerning the results of existing studies, we set consistency threshold to 0.8 and case frequency threshold to 1, thereby constructing and analyzing the truth table to obtain complex solutions, intermediate solutions, and simple solutions. As the intermediate solution only incorporates logical residual terms that align with theoretical expectations and practical empirical evidence, complexity is moderate, and necessary conditions cannot

be eliminated. Therefore, in this study, we mainly use the intermediate solution, supplemented by the parsimony solution, to determine the core edge conditions of different configurations. At the same time, keeping other conditions unchanged, the study also increases consistency level from 0.78 to 0.85, and configuration results produced are entirely consistent. The specific configuration paths and their explanatory case distributions are detailed in Table 3 and Figure 2. Based on the existence of configuration condition variables in technology, organization, and environment, we have identified three driving paths for effectiveness of high-level public health emergency governance. Each column in Table 3 represents a possible condition configuration path. In addition, consistency level of both the single solution and the overall solution is higher than that of the standard value, 0.75, and consistency of the three condition combinations is 1, indicating that the condition combination has high explanatory power for the outcome variable.

Configuration 1 indicates that existence of a data-sharing platform plays a central role. Compared with other conditions, data-sharing platforms are more important for effectiveness of high-level emergency governance and can independently constitute sufficient conditions for interpreting results. Under this condition configuration, when there is a data-sharing platform, other conditions are irrelevant to the effectiveness of

Table 1. Calibration of conditions and results

Conditions	Conditions and results	Calibration Anchor Point		
		Completely affiliated	Intersection point	Completely non-affiliated
Outcome Variable	Public health emergency governance effectiveness	15.199	13.15	9.536
Technical conditions	Introduction of emerging technologies	6.01	5.01	2.1
	Data-sharing platform	6.9	4.01	3.01
Organizational conditions	Organizational system guarantee	37	8.01	3.1
	Government attention allocation	138.4	361.01	729.09
Environmental conditions	Data application scenario integrity	4.01	3.01	2.01
	Data elements market development index	88.04	62.71	40.44

Table 2. Necessity analysis results

Condition variables	High public health emergency governance effectiveness		Low public health emergency governance effectiveness	
	Consistency	Coverage	Consistency	Coverage
Introduction of emerging technologies	0.6284	0.6730	0.6667	0.6125
~Introduction of emerging technologies	0.6381	0.6905	0.6441	0.5979
Data-sharing platform	0.7463	0.7446	0.6149	0.5262
~Data-sharing platform	0.5250	0.6138	0.7015	0.7035
Organizational system guarantee	0.7609	0.8322	0.5603	0.5256
~Organizational system guarantee	0.5662	0.6002	0.8211	0.7466
Government attention allocation	0.5412	0.6788	0.6102	0.6565
~Government attention allocation	0.7262	0.6847	0.7015	0.5674
Data application scenario integrity	0.5767	0.7104	0.5951	0.6288
~Data application scenario integrity	0.6987	0.6680	0.7260	0.5954
Data elements market development index	0.7068	0.7682	0.4840	0.4513
~Data elements market development index	0.4952	0.5280	0.7514	0.6873

Table 3. Configuration paths for high-level public health emergency governance effectiveness

Conditional configuration	Technical-based	Organization-environment dual core	Organization-technology as the mainstay + environment as the supplement	Robustness test
	Configuration 1	Configuration 2	Configuration 3	Configuration 4
Introduction of emerging technologies	⊗	⊗	●	●
Data-sharing platform	●	⊗	●	●
Organizational system guarantee	⊗	●	●	●
Government attention allocation		●	●	●
Data application scenario integrity	⊗	●		
Data elements market development index	⊗	●	●	●
Consistency	0.8852	0.8854	0.8396	0.8306
Original coverage	0.2617	0.2746	0.4483	0.4830
Unique coverage	0.0840	0.0517	0.2189	0.4830
Consistency of the overall solution			0.8489	0.8306
Coverage of the overall solution			0.6082	0.4480

Note: ● or ● means that the condition exists, ⊗ or ⊗ means that the condition does not exist. ● or ⊗ means the core condition, ● or ⊗ means the edge condition, and blank means that the existence of the condition is irrelevant to the result.

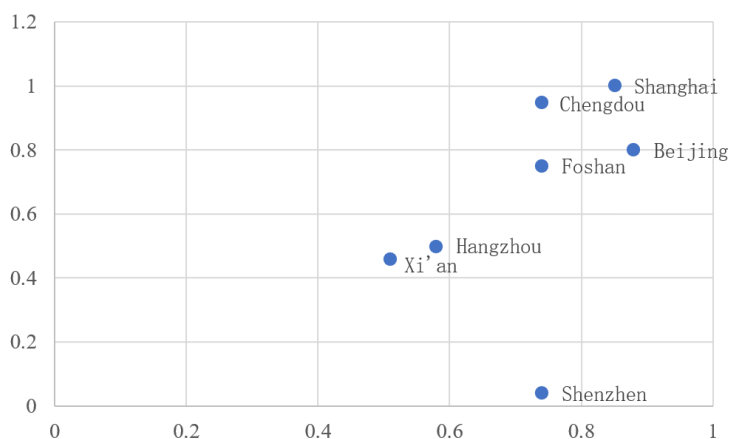


Figure 2. Distribution of explanation cases of configuration paths.

high-level emergency governance, so this path can be summarized as "technology-based". This means that establishing a data-sharing platform can systematically integrate information related to public health prevention and control, promote cross-departmental, cross-level, and cross-regional risk communication and collaborative efforts, address multiple bottlenecks in cross-border information, break through constraints of internal and external conditions such as organization and environment on local governments, and improve effectiveness of emergency governance of public health emergencies. The consistency of this configuration is 0.8852, and the original coverage rate is 0.2617, which can explain about 26.17% of emergency governance cases of urban public health emergencies. For example, in the face of public health emergencies, Foshan has built data-sharing platforms such as "Foshan Epidemic Prevention Information Live Broadcast System" and "Epidemic Special Module of Cooperative Office System" within six days, overcoming difficulties of incomplete systems, untimely government decisions, and limited scenario applications.

Configuration 2 indicates that organizational and

environmental factors play a central role. In cities with rich data application scenarios and data element markets, when emerging technology methods are not introduced enough and data-sharing platforms are not perfect, with attention and support of government agencies at all levels, risk information scattered in multiple departments such as Emergency Management Agency, Health Commission, and Centers for Disease Control and Prevention should be coordinated to strengthen integration and utilization of cross-departmental data. Local governments can also quickly adjust their decision-making plans and improve their level of risk management. Considering that this driving path consists of four conditional elements: organizational system assurance, government attention allocation, application scenario integrity, and data element market development level, this path can be summarized as the "organization-environment dual core". Consistency of this configuration is 0.8854, with an original coverage rate of 0.2746, which can explain approximately 27.46% of urban public health emergency governance cases. For example, the "Implementation Opinions on Improving the System and Mechanism for Major Epidemic

Prevention and Control and Improving the Emergency Management System for Public Health Emergencies" in Chengdu City point out that it is necessary to rely on big data to establish a monitoring and early warning system and a linkage response and disposal mechanism between early warning departments, strengthen timely investigation and verification, and synchronously initiate early control measures.

Configuration 3 indicates that in the process of orderly promoting marketization of data elements, even if application scenarios of data elements are not diverse enough, high-level emergency governance efficiency can be achieved by fully introducing emerging technologies, building data-sharing platforms, providing organizational and institutional guarantees, and giving sufficient attention to the government. Among them, introducing emerging technologies, data-sharing platforms, organizational and institutional guarantees, and government attention allocation are all core conditions, with the development level of the data elements market playing a supporting role. Therefore, it can be summarized as "organization-technology as the mainstay + environment as the supplement". The consistency of this configuration is 0.8396, with an original coverage rate of 0.4483, which can explain approximately 44.83% of urban public health emergencies and emergency governance cases. For example, Beijing Emergency Command Center, as the only institution in China that undertakes the "three in one" work responsibilities, strengthens intelligent scheduling and big data analysis, and through the introduction of advanced information technology, collects and analyzes a large amount of urban operation data, predicts and evaluates potential risks, and achieves rapid response and efficient handling of various emergencies.

4.3. Robustness test

This article conducted a robustness test on the antecedent configuration of high-level emergency governance effectiveness. First, while keeping other conditions constant, the consistency level increased from 0.78 to 0.85, resulting in consistent configuration results. Then, drawing on the research methods of Zhang and Du (2019) (22), the case frequency threshold was adjusted from 1 to 2. The results indicate that when the number of cases is less than the threshold of 2, configurations 1 and 2 are removed as logical residues, but the resulting configuration 4 still belongs to a subset of the original configuration path set (see configuration 4 in Table 3). Therefore, the results of this study are generally robust.

5. Discussion

Drawing on the public health emergency governance practices of 23 mega-cities in China, this article examines the complex causal mechanisms through which various

factors influence data elements empowerment and drive governance effectiveness, adopting a configurational perspective. The results show a significant conditional correlation between urban emergency governance effectiveness and data elements application conditions. The driving paths can be classified into three categories: "technology-based", "organization-environment dual core", and "organization-technology as the mainstay + environment as the supplement". To fully leverage the multiplier effect of data elements, unlock their latent value, and strengthen emergency governance capacity of urban public health, we propose the following suggestions based on our research findings.

First, following configuration 1, efforts should be made to promote interconnection of data-sharing platforms, and to streamline the entire process of technology adoption and output. As the core production element of the digital economy, data's value hinges on the cross-departmental sharing and utilization of information resources. Building an interconnected cross-departmental data-sharing platform is the core of achieving data empowerment. By establishing a comprehensive public health emergency governance platform that integrates cross-departmental data, governance objectives, and operational needs, and by embedding digital technology throughout the technology output process, fragmented data scattered across vertical and horizontal organizational units can be fully opened up—creating a new paradigm of networked circulation.

Second, following configuration 2, institutional coordination must be strengthened to accelerate multi-scenario applications of data elements. In the emergency governance of urban public health, this entails constructing integrated urban emergency command centers to coordinate cross-departmental operations, allocate emergency materials, equipment, and personnel, and effectively dismantle organizational barriers to data elements empowerment. Leveraging the "full-chain" attributes of data applications, data elements should be flexibly deployed across diverse scenarios, including epidemic risk screening, case early warning, and outbreak response coordination, to enhance scientific identification, precise assessment, professional evaluation, and efficient management of public health safety risks.

Third, following configuration 3, the dual drivers of technological advancement and organizational coordination must be reinforced to improve emergency response efficiency. Full realization of data element value depends jointly on technical sophistication and organizational synergy. We should leverage advantages of emerging data technologies in integration and clustering analysis to generate massive and dynamic urban public health and safety data, promote deep connections between different organizations through data streams, further facilitate effective integration of organizational information, and create favorable conditions for the

role of data elements in urban public health emergency governance.

In conclusion, research on data elements in urban public health emergency governance remains in its early stages. Given that public health emergency governance is a dynamically evolving process, we acknowledge certain limitations in assessing its effectiveness. Specifically, the selected indicators do not directly capture process-level performance, such as response speed and coordination efficiency. Future research will place greater emphasis on tracking temporal and regional variations in governance effectiveness. It will further explore applicability of data-driven approaches while balancing data privacy protection with open sharing, thereby advancing scientific and orderly integration of data elements into urban public health emergency governance and comprehensively enhancing overall effectiveness.

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