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Enlightenments and Challenges of Public Health Emergencies to Public Utility Management

Qiyu Wu

School of Public Health, Kunming Medical University, Kunming, China
2639805735@qq.com

Abstract. This study focuses on the comprehensive impact and profound enlightenment of major public health emergencies on the public utility management system. By analyzing the shocks exerted by public crises on public sectors such as medical care, lifeline engineering, transportation and logistics, and environmental sanitation, it exposes the systemic shortcomings of traditional management models in redundancy design, cross-departmental collaboration, and forward-looking decision-making. To address these challenges, the research points out that public utility management needs a fundamental transformation, with the core being the construction of a new structure targeting "resilience". This requires embracing the principle of "integration of peacetime and emergency management" in philosophy, deeply integrating digital technology in practice to achieve intelligent scheduling and precise response, and integrating the multiple forces of government, market, and society at the governance level. This study provides theoretical reference and practical paths for exploring the risk resistance and sustainable operation of the public utility system in the post-pandemic era.

Keywords: Public health emergencies, Public health management, Crisis reshaping, Data-driven

1. Introduction

Since the new century, major public health emergencies have emerged one after another globally, posing a continuous test to modern social governance capabilities. Whether it is the 2003 SARS epidemic in East Asia, the 2014 Ebola virus crisis that devastated West Africa, or the COVID-19 pandemic that has profoundly changed the global pattern since late 2019, these events have exceeded the scope of mere medical and health care and evolved into a comprehensive test of social basic support networks. Public utility management is the core pillar for maintaining the normal operation of modern society, covering the supply of public services in fields such as water, electricity, gas, transportation, medical care, and environmental sanitation. Essentially, it provides basic public goods and services for society through the collaborative operation of the government, social organizations, and market entities [1,2]. Public health emergencies have exerted an all-round impact on the public utility management system from four aspects: failure of early warning and monitoring, disruption of supply guarantee, obstacles to information collaboration, and insufficient system resilience. They have not only pinpointed the shortcomings of the traditional risk perception

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system being lagging and rigid, but also highlighted the inherent deficiencies of critical infrastructure in emergency transition, resource allocation, and cross-regional linkage, and further reflected the institutional rigidity and insufficient flexibility of the current management system in responding to complex and volatile risks [3].

Establishing a more resilient, intelligent, and collaborative resilient management system is not only a necessary measure to address future uncertainties, but also an inherent requirement for realizing the modernization of national governance capabilities. Therefore, the core question of this paper focuses on: through triggering structural mutations in demand, systemic disruptions in supply chains, and failures in cross-departmental collaboration, public health emergencies have comprehensively impacted the traditional public utility management model centered on "stable supply" and "scale efficiency". How to optimize the existing management model, build a more resilient public utility management system, achieve prediction of complex scenarios and precise and flexible scheduling of resources, and form an intelligent and resilient public utility management system with shock resistance, rapid recovery, and sustainable evolution capabilities. The theoretical significance of this study lies in helping to reveal the behavioral mechanism and evolution law of complex public systems under pressure. The practical significance is that by exposing systemic shortcomings and proposing resilience construction paths, it can provide decision-making basis for the government and different public utility departments to improve emergency efficiency and optimize resource allocation. At the same time, it can promote the digital transformation of public utilities and explore the establishment of flexible and standardized public-private cooperation and social mobilization mechanisms to absorb broader social resources to address future uncertainty challenges. Ultimately, it aims to build a bottom-line safety net for social survival and development and contribute wisdom to enhancing the overall "immunity" of society against major risk shocks.

2. Literature review

2.1. Research on public health emergencies

Major public health emergencies constitute a complex systemic crisis. Studies by Kickbusch and Reddy [1] have revealed how public health emergencies become a touchstone for testing the effectiveness of governance structures, pointing out that coordination failures and insufficient political will are the core reasons for early response failures. Smith [4] and others used quantitative models to confirm that major infectious diseases will have a sustained negative impact on the supply of basic public services by impacting the labor market and fiscal system. By comparing the different logics of China and the United States in responding to COVID-19, Wang Lei and Wang Qingyun [5] pointed out that although "rigid governance" can achieve rapid social mobilization and control, it lacks flexibility, and thus proposed building a new model of "resilient governance". Dong Yuqiong and others [6] constructed a reactive scheduling optimization model considering the dynamic changes of medical resources, and their research provides a scientific decision-making tool for minimizing rescue costs and maximizing efficiency under resource constraints. In addition, through case studies on crisis leadership in multiple countries, Boin and 't Hart [7] emphasized that successful emergency response depends not only on pre-formulated plans, but also on decision-makers building cross-departmental alliances and conducting effective political communication in a highly uncertain environment, which highlights the core role of leadership and collaborative governance in crises.

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2.2. Research on public utility management

Research on public utility management has gradually expanded from focusing on institutional design and management efficiency to exploring system resilience and governance models. Wang Luozhong and Qin Ying [8] were among the first to focus on institutional issues in China's public crisis governance and proposed a reform path of integrating resources by establishing authoritative decision-making bodies and building information sharing platforms. From the practical perspective of talent training, Zhang Ning and others [9]demonstrated that strengthening managers' medical and health knowledge and practical capabilities is the foundation for addressing complex health governance challenges and improving the professionalization level of public services. Francis and Bekera [10] developed a resilience analysis framework and measurement method, proposing that the resilience of engineering infrastructure should systematically evaluate its composite capabilities of absorbing shocks, adapting to changes, and recovering quickly, providing a tool for quantitatively assessing the vulnerability of public utility systems. Chelleri and others [11] advocated that resilience planning for urban infrastructure must go beyond a single engineering perspective to simultaneously improve the reliability of technical systems and the adaptive capacity of communities. Through comparative case studies of multiple public utility departments, Giest and Samuels [12] found that the application of big data analytics can realize cross-institutional data integration and intelligent analysis, thereby promoting the transformation of public services to a precise and preventive "seamless" collaborative model and significantly enhancing the overall resilience of the system.

Based on the above research, public health emergencies refer to urgent situations that occur suddenly and pose a serious threat to group health and social order. Their characteristics are: suddenness, exceeding conventional monitoring and prediction capabilities; group nature, affecting a wide range with public attributes; complexity, whose evolution is deeply intertwined with multiple factors such as society, economy, and environment, forming cross-domain systemic challenges. Public utility management refers to the process of systematically organizing, supplying, and optimizing basic public services such as water, electricity, transportation, medical care, and environmental sanitation. In the context of a risk society, the goal has been expanded to building a resilient governance system, that is, by improving the system's ability to absorb shocks, adapt to changes, and recover quickly, and leveraging digital technology to achieve intelligent collaboration, ensuring the continuous and reliable operation of basic services.

3. Analysis of impacts and challenges of public health emergencies on public utility management

3.1. Impact on public medical service management

Major public health emergencies trigger an explosive growth in medical demand, leading to simultaneous shortages of intensive care beds, key equipment, and professional medical staff. This extreme imbalance and structural mismatch between supply and demand put the treatment system at risk of collapse under peak pressure, forcing the suspension of routine medical services and triggering other challenges.

In terms of resource load, during the domestic epidemic peak, the occupancy rate of ICU beds exceeded 100%, operating beyond capacity; the ratio of frontline intensive care nurses to patients deteriorated to 1:4-1:5. International data shows that the ICU occupancy rate in many countries exceeded 95%, and even reached 250% in some regions; the average daily working hours of medical

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staff generally increased to 12-16 hours, and the rate of occupational burnout rose significantly. In terms of supply chain pressure, at the initial stage of the epidemic, the inventory of protective materials in key domestic hospitals could only last for less than 1 day, and the consumption rate of core protective supplies soared to more than 100 times the normal level. During the same period, the global supply chain fell into chaos: the short-term price of N95 masks in the United States soared by more than 60 times, and the actual delivery volume was less than 10% of the demand. The global order delivery cycle for key equipment such as ventilators was forced to shrink from the normal 3-4 months to 1.5-2 months, and market prices generally rose by 3-5 times, but supply still failed to meet demand.

3.2. Challenges to the management of lifeline engineering such as water, electricity, gas, and information and communication networks

The surge in residential load coexists with the sharp drop in industrial and commercial load, leading to disordered peak-valley characteristics of the system. At the same time, fault response is delayed, preventive maintenance is lacking, and the potential risks of system operation increase. The disruption of global and regional supply chains poses a profound threat to the long-term stability of the system.

There has been a structural mutation in demand patterns. In terms of water and electricity consumption, during the epidemic lockdown period, the monthly-on-month growth rate of residential water consumption in Wuhan, Beijing and other places reached 25%-28%. In terms of electricity load, residential electricity consumption increased significantly by 20%-30%, while the electricity load in industrial intensive areas dropped by as much as 51%-63%, putting great peak-shaving pressure on the power grid. In the field of information and communication, national mobile data traffic surged by 45.5% year-on-year, while corporate dedicated line demand decreased by 38%-42%, and network traffic underwent a large-scale spatiotemporal migration from commercial centers to residential areas. The operation and maintenance support system is under tremendous pressure. The fault repair response time of various systems generally increased by 120%-250%. For example, the response time of Beijing Power Grid and national broadband networks extended from several hours to more than 2.5 times the original. More critically, the coverage rate of preventive inspections dropped by 25-35 percentage points, and a large number of hidden dangers could not be detected and addressed in a timely manner. The stability of the supply chain has been severely impacted. The supply cycle of key materials has generally extended to three times the normal level, exposing serious shortcomings of the system in dynamic scheduling, flexible operation and maintenance, and supply chain resilience when facing global crises.

3.3. Challenges to public transportation and logistics management

Strict prevention and control measures have led to a cliff-like drop in public transport passenger volume, with a large number of idle capacity in systems such as subways and buses, and a sharp decline in operating income. The demand for the distribution of epidemic prevention materials and people's livelihood materials has exploded, putting enormous pressure on the urban terminal logistics system. This extreme contradiction of "one cold and one hot" poses an unprecedented test to the system's overall scheduling and flexible adaptation capabilities.

Passenger transport intensity has suffered a devastating impact. As shown in Table 1, during the strict epidemic control period, the public transport passenger volume in major cities plummeted by

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80% to 99% compared with normal days. Ground bus and intercity passenger transport shrank, and the urban passenger transport system was basically in a "frozen" state.

Logistics efficiency has been significantly reduced due to systemic obstacles. In sharp contrast to the "cold" passenger transport, the logistics terminal that guarantees urban operation is extremely "congested". Due to cross-regional traffic control and strict epidemic prevention inspection procedures, the efficiency of the entire logistics chain has been greatly delayed. The urban distribution of medical materials extended from several hours to 1-2 days; the delivery time of people's livelihood materials such as fresh e-commerce generally delayed from "next-day delivery" to 5-7 days. The traffic efficiency at key nodes dropped sharply by 66%-90%. The average passing time of vehicles at highway toll stations and community checkpoints extended from a few minutes to more than ten or even thirty minutes, seriously restricting the response speed of the overall supply chain.

Table 1. Deterioration of key logistics efficiency indicators during the epidemic

Indicator Category	Specific Scenario	Normal Efficiency	Efficiency During the Epidemic	Decline/Delay Situation
Delivery Time	Medical materials (Wuhan)	Delivery within 4-6 hours	Delivery within 24-48 hours	Delayed by 20-42 hours
	Fresh materials (Shanghai)	Delivery within 24 hours	Average delivery in 5-7 days	Delayed by 4-6 days
	E-commerce parcels (national)	Cross-provincial delivery in 3-5 days	Cross-provincial delivery in 7-15 days	Delayed by 4-10 days
Node Traffic	Provincial highway toll stations	1-2 minutes/vehicle	10-15 minutes/vehicle	Traffic efficiency dropped by 80%-90%
	Urban community delivery checkpoints	3-5 minutes/vehicle	20-30 minutes/vehicle	Traffic efficiency dropped by 83%-90%
	Airport freight security inspection	2 hours/batch	6-8 hours/batch	Traffic efficiency dropped by 67%-75%
	Port container turnover	2-3 days/container	7-10 days/container	Turnover efficiency dropped by 67%-70%

3.4. Challenges to urban environmental sanitation and waste management

The surge in medical waste far exceeded daily processing capacity, posing an extreme challenge to emergency response; the structure and quantity of domestic waste underwent drastic changes, impacting the waste classification system; frontline environmental sanitation workers were exposed to high-risk environments due to the nature of their work, with prominent issues of protection guarantees and work load.

In terms of the surge in medical waste: the medical waste generation in many cities reached 3 to 10 times the daily level during the epidemic peak. For example, the daily processing volume in Wuhan at the peak in early 2020 was approximately 420 tons, 10.5 times the daily level of 40 tons. At the national level, the daily medical waste generation during the peak period could reach 3 to 5 times the daily level. In terms of domestic waste treatment: the proportion of kitchen waste among residents increased significantly from about 25-30% in normal times to 40-45%; at the same time, the recycling volume of recyclables dropped sharply. This directly led to the load rate of terminal

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treatment facilities surging from about 75-80% in normal times to 90-95%. To maintain operation, incineration plants in many places had to start standby production lines and operate 24 hours a day. In terms of the risks and emergency capabilities of environmental sanitation workers: there was once a 30-40% gap in protective materials for frontline environmental sanitation workers, and their average daily working hours also extended to 12-14 hours. Their infection risk was about 4.5 to 7 times that of the general population. To address the capacity gap, the country urgently added new treatment capacity accounting for about 20% of the total treatment demand by expanding facilities and deploying mobile equipment, but the treatment system still operated at a high level for a long time.

4. Directions for reshaping public utility management from crises

4.1. Innovation in management philosophy

Traditional public utility management pursues optimal cost and stable operation in a predictable environment. However, data such as ICU bed occupancy rate exceeding 100%, key material supply cycles tripling, and logistics time delays of several days to weeks during the epidemic all declare the failure of this "rigid stability" thinking under sudden shocks. Future management needs to shift from pursuing static efficiency to building dynamic adaptation and rapid recovery capabilities, investing in necessary public areas based on quantitative risk assessment. For example, the medical system needs to establish a dynamic bed and material reserve mechanism based on peak pressure calculations; power grids and water networks need to plan modular emergency units that can be quickly activated; the logistics system can preset "green channels" and alternative routes. This "resilience investment" serves as an "insurance" to ensure the basic operation of society and avoid systemic collapse during crises. Its core is to shift from passive "post-disaster response" to active "pre-event adaptation" and "in-event pressure resistance", and from "stable operation" to "integration of peacetime and emergency management" and "resilience construction".

4.2. System restructuring

Fragmented management is one of the biggest obstacles to crisis response. During the epidemic, information barriers in the interaction between medical care, transportation, energy, and communication led to resource mismatch and delayed response. Therefore, building an intelligent and integrated public utility emergency collaboration network can integrate multi-source information such as infectious disease monitoring, urban operation, and resource inventory in real time through the Internet of Things and global data integration. For example, combining epidemic development maps, population flow data, and warehousing information, a dynamic material demand prediction and allocation model can be constructed to achieve a shift from "passive allocation" to "active pre-positioning". When the risk in a certain area escalates, the system can automatically trigger an early warning and simultaneously prompt the power department to ensure power supply to key facilities, the transportation department to plan material transportation routes, and the environmental sanitation department to adjust medical waste collection and transportation plans. This "one-stop" collaboration based on a unified information base can upgrade cross-departmental collaboration from a temporary model to a normalized automated response, building an intelligent and integrated public utility emergency collaboration network.

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4.3. Technological empowerment

Big data and artificial intelligence technologies are becoming the key drivers for transforming public utility management from "experience-based judgment" to "data-driven" decision-making. At the prediction and early warning level, machine learning models can be used to integrate multi-dimensional data such as virus transmission, meteorological conditions, and social networks to conduct forward-looking simulations of epidemic development trends and their impact on the demand of various sectors such as water, electricity, and transportation. For example, AI models can predict changes in electricity load, medical waste generation, or network bandwidth demand in different residential areas under various scenarios in the next week, providing precise guidance for resource pre-positioning. At the operation and maintenance support level, digital twin technology can build a virtual mirror of critical infrastructure, conduct health diagnosis and risk prediction through continuous data mapping, and realize preventive maintenance. In logistics scheduling, advanced algorithms can calculate the optimal delivery route in real time under traffic control constraints, alleviating the dilemma of traffic efficiency at community checkpoints dropping by more than 80%. Technological empowerment can achieve more precise flexible scheduling and lower operational risks.

4.4. Social participation

A single government entity cannot take on all emergency affairs. During the epidemic, professional logistics companies, e-commerce platforms, and volunteer organizations played an irreplaceable role in terminal delivery. Establishing a government-market-society multi-stakeholder governance model, the government takes the lead in building an open and credible public data sharing and task release platform. Through the platform, the government can release authoritative information such as material needs, capacity gaps, and volunteer services in real time; market enterprises can connect resources with their professional efficiency (such as warehousing and distribution); social organizations can accurately mobilize and match volunteers. For example, the "volunteer logistics platform" model can be learned from to dynamically match data on idle passenger buses and social vehicles with the demand for medical material distribution. At the same time, policy tools such as service procurement, tax incentives, and insurance guarantees are needed to encourage and ensure the sustainable participation of market and social forces. This multi-stakeholder governance model can effectively organize massive resources and tiny forces scattered in society, enhancing the overall resilience and recovery capacity of society.

5. Data-driven countermeasures and suggestions

5.1. Constructing a "digital twin" and risk early warning system for public utilities

To address the backward and rigid traditional risk perception, it is urgent to build a city-level "digital twin" system covering core public utilities. This system can integrate multi-source heterogeneous data from IoT sensors, municipal operations, population flow, environmental monitoring, and even the infectious disease network direct reporting system, thereby changing the plan formulation and decision-making model. Managers can simulate different levels of public health emergencies or other disaster scenarios in a virtual space to accurately identify network vulnerable nodes and resource allocation bottlenecks. For example, under a scenario similar to the 2022 Shanghai epidemic peak (daily medical waste output reaching 7 times the normal level), the pressure-bearing

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limit of the existing transportation and treatment facilities can be simulated and deduced, and the optimal emergency response plan can be automatically generated. Thus, risk management is transformed from post-event tracing and passive response to active defense based on simulation and deduction, providing a precise decision-making sandbox for "integration of peacetime and emergency management".

5.2. Establishing a dynamic reserve of key resources and a resilient supply chain

The epidemic exposed the powerlessness of the static and rigid reserve system under soaring demand. Dynamic reserve coefficients for various key resources should be set based on historical peak data, population density, regional risk levels, and prediction models. For example, for medical protective clothing, N95 masks and other materials in key cities, their strategic safety inventory should be increased to 150%-200% of normal consumption, combined with a management mechanism of "rolling consumption and regular updating". At the same time, blockchain and IoT technologies are used to build a full-process traceable supply chain system, establish "flexible contract" relationships with multiple suppliers, and preset rapid production capacity conversion and logistics priority channels in emergency situations. Through "real-time data + flexible contracts", this system ensures that when the supply chain is partially interrupted, the backup network can be quickly activated, and the supply cycle of key materials can be controlled within an acceptable limit.

5.3. Formulating precise, hierarchical and classified emergency response plans

Formulating quantitative and differentiated hierarchical response plans can improve the accuracy and collaboration efficiency of emergency responses. The plan should quantitatively link the early warning level of public health emergencies (Level IV, III, II, I) with the specific operation and control indicators of each subsystem of public utilities. For example, when Level III response (regional risk) is activated, the subway passenger flow control target is automatically set to no more than 50% of the normal level, and 30% of bus capacity needs to be reserved for conversion into emergency material distribution fleets; when upgraded to Level II response (high risk), the "people's livelihood guarantee first" model is activated, such as clearly defining the percentage of industrial and commercial water use restrictions while giving priority to guaranteeing key users such as hospitals. This data-based plan transforms emergency response from vague administrative orders into clear and automatically triggerable standardized operating procedures, improving the efficiency of cross-departmental collaboration.

5.4. Improving the management performance evaluation system with resilience as the core

The performance evaluation of traditional public utility management mainly focuses on efficiency, cost, and normal reliability, which is no longer sufficient to guide the resilience development of the system. It is necessary to reform the performance evaluation system and establish key performance indicators (KPIs) for resilience.

The new KPIs should include: system recovery time, such as "the median time required for core service functions to recover to 90% level from damage (TTR)"; resource allocation efficiency, such as "the allocation accuracy and timeliness rate of key resources from warehouses to demand points in emergency situations"; extreme scenario guarantee degree, such as "the guarantee coverage rate of lifeline services for the population in core urban areas under a simulated once-in-a-century shock scenario". In addition, the system's learning and evolution capabilities should also be evaluated. By

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incorporating such resilience indicators into the annual assessment and audit of government and public utility institutions, resources can be continuously guided to areas that enhance the long-term safety and adaptability of the system, promoting the resilience optimization of public utility management.

6. Conclusions and prospects

6.1. Main research conclusions

This paper conducts research from three dimensions: the challenges of public health emergencies to public utility management, how to optimize public utility management, and how to optimize public utility management from a data-driven perspective. It systematically analyzes the impacts of public health emergencies on four major public utility fields: medical care, lifeline engineering, transportation and logistics, and environmental sanitation. It proposes optimization paths for public utility management including innovation in management philosophy, system restructuring, technological empowerment, and social participation, and establishes data-driven early warning systems, supply chains, emergency plans, and KPIs, providing suggestions for the modernization transformation of public utility management.

6.2. Research limitations and prospects

First, the in-depth integration and application of artificial intelligence in extreme scenario prediction. In the future, more advanced AI models can be explored to simulate the superimposed effects of public health emergencies and compound crises such as extreme weather and cyber attacks, providing stronger decision support for resilience planning. Second, research on mechanisms and data standards for cross-regional public utility collaborative emergency response. In the future, it is necessary to conduct in-depth research on how to establish cross-administrative regional emergency linkage command mechanisms, cost sharing and compensation methods, and achieve interconnection and standard unification in key data such as infrastructure status, resource inventory, and emergency teams. Third, research on organizational behavior and micro-foundations. Resilience is not only about technology and hardware, but also depends on the capabilities of organizations and individuals. In the future, attention can be paid to the micro-behavioral mechanisms of emergency decision-making in crisis scenarios, and research on how to improve the on-the-spot decision-making capabilities and rapid learning capabilities of frontline institutions through organizational culture shaping, incentive mechanism design, and systematic training, thereby consolidating the micro-foundations of resilient governance.

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