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Development of Intelligent Response to Public Health Emergencies

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Abstract: An informationized, digitalized, and intelligent emergency response mode is currently required in China to address the weaknesses and low efficiency of public health emergency management in terms of quick response mechanisms, multi-department collaborations, and information interactions, which can promote the response capabilities of China's public security sector. A descriptive research method is adopted to analyze the status quo of public health emergency response systems and intelligent emergency response development in other countries and to summarize the requirements, status, and main problems of public health emergency management in China. Development goals, major research tasks, and technological approaches have also been proposed. To develop a preventative public health emergency response network in China, we suggest that a major national biological monitoring and early warning project be established for enhancing public health emergency responses, the relevant laws and regulations be promulgated and revised, the data integration and sustainable development of the emergency management mechanism be maintained, an intelligent public health emergency response industry be encouraged, and the efforts of the professionals providing medical care and preventive medicine be integrated.
Keywords: intelligent emergency response; monitoring and early warning; emergency operation; integration of medical care and prevention

1 Introduction

Enhanced mobility and more frequent economic interactions in various countries have escalated the risk of spreading and transmitting infectious diseases [1]. Public health emergencies, which are occurring at an increased frequency, have attracted intense attention because of their impact on China's economy and society. In recent years, the rapid development of a new generation of information technology (IT), including the Internet, big data, and cloud computing, has triggered major changes in the development model of many industries in China. With the further integration of big data and artificial intelligence (AI) into the economy and society, smart emergency-response industries are increasingly demanded [2].

The national strategy of Internet Plus Healthcare has played a significant role in the prevention and control campaign launched against the COVID-19 pandemic. It is predicted in some research [3,4] that, by the year 2030, China will lead the world in the theory, technologies, and general application of AI. To achieve the goal of establishing a society with residents' health as the centerpiece and a strong public health system underpinned by an enhanced national bio-security concept in 2035, building an intelligent system in response to emergencies must be

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regarded as a strategic orientation based on the deep integration of the fifth generation of communication (5G), AI, big data, cloud computing, and other types of next-generation IT into the management of emergent public health events. As an instrument, IT is applied to multi-channel surveillance and early warning, highly efficient science-based smart command and decision-making processes, and other links of health emergency management for the purpose of upgrading China's scientific, professional, and economic levels of public health emergency management.

In retrospect, in terms of the response to COVID-19, not only have weak links and shortcomings related to the application of big data and information interactions in conventional public health emergency systems been identified, but a new generation of IT has also proved that technology has a promising role to play in tracing the origin of the virus, imposing quarantines, and carrying out highly efficient science-based treatments. Therefore, this paper presents macro-research targeting the innovative application of smart responses to public health emergencies, striving to propose medium-to-long-term development goals, major tasks, and technical paths for China's smart response and management system for emergencies in the hope that it might serve as a fundamental reference for forward-looking development in relevant fields.

2 Analysis of demands for smart responses to emergencies

In recent years, thousands of events have been recorded in China, with the emergent incidents stemming mainly from infectious diseases, which are characterized by abruptness, huge damage, and widespread issues. Infectious diseases, especially ones causing major outbreaks, such as the plague, H1N1, and COVID0-19, severely threaten people's health and lives and disturb social stability and economic development.

The key to dealing with an outbreak is to focus on addressing issues such as blocked channels, delayed information, and low efficiency while guaranteeing timely data collection, reporting of issues, science-based analysis and judgment, highly efficient instruction, and decision-making based on data and information. Issues—regarding infectious disease surveillance and early warning, transmission model identification, trend judgment, pandemic reporting and information-based management, epidemiological surveys, visualized displays and analysis, and community management—were laid bare by the outbreak of COVID-19 and should be urgently addressed.

Owing to the rapid development of a new generation of IT, including the Internet, IoT, 5G, big data, cloud computing, and AI, it is necessary to delve deeper into applying these new technologies to emergency management, rapidly upgrade information-based responses to handle emergencies, and devise innovative management models for emergencies to further develop smart projects in response to such events and boost management capabilities in health emergencies.

3 Progress in overseas health emergency preparedness

3.1 The United States

The National Incident Management System of the United States provides a uniform format across the nation for coordinating the efforts of various departments and requires all states and local governments to respond to incidents accordingly [5]. The U.S. Centers for Disease Control and Prevention (CDC) has always prioritized the development of a public health information system that consists of 101 surveillance systems divided into 28 categories, among which those relevant to public health emergency incidents are the National Surveillance System of Infectious Diseases, Electronic Laboratory Reporting System (collecting electronic laboratory information and reports), and the National Syndromic Surveillance Program (for timely analysis and comparison of data) [6]. In 2004, the Department of Homeland Security introduced the National Bio-Surveillance Integration System Program to collect, integrate, and analyze information on human diseases, food, agriculture, water, meteorology, and environmental surveillance with the aim of enabling early detection of outbreaks or incidents of natural diseases, intentional utilization of biological agents of warfare, and new occurrences of biological hazards. In 2012, the United States released the *National Strategy for Biosurveillance*, aiming to establish a highly efficient and integrated national system for biosurveillance to collect crucial full-spectrum information on human and animal threats to construct an early warning system for biological threats and facilitate an overall situational awareness of public health emergencies [7]. The United States also proposed a goal of developing an intelligent national surveillance system for occupational health to ensure the quality and efficiency of surveillance data as well as information security. Data collection, analysis, and displays must follow a set of standards that require the participation of experienced personnel [8].

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3.2 Other countries

In 2012, the World Health Organization (WHO) initiated EOC_Net, which is widely applied in emergency centers in many countries and plays an important role in responding to public health incidents [9,10]. In the European Union (EU), Australia, and some other countries and regions, the WHO and other international organizations either erected an independent system to provide guidance and instructions in health emergencies or put into place a sub-system for responding to public health emergencies while following instructions from the government. The public health emergency preparedness of the European Center for Disease Prevention and Control (ECDC) has led to the development of many special tools for information management, such as tracing and tracking tools for risk surveillance and evaluation, an early warning and response system for coordinating responses, and an intelligent system for risk evaluations of infectious diseases. The ECDC has worked with EU member states to establish a fast-response and early warning system and signed agreements on terminology and protocols to realize uniform operation as well as information exchange and sharing.

Generally, there are impressive practices overseas regarding the application of IT to public health emergency preparedness. However, as "smart responses to emergencies" remains a new concept reflecting a new starting point, the establishment of a comprehensive system of intelligent responses to emergencies is still in the fledgling stage in many countries.

4 Status quo of public health emergency preparedness in China

4.1 Accomplishments

First, the management and operation of systems for responding to public health emergencies have continuously improved thanks to gradual progress in laws, regulations, and institutions in terms of public health emergency preparedness and the presence of a sound prearrangement system. Over 70 laws and regulations, including the *Emergency Response Law of the People's Republic of China* and 10-odd ministerial rules and a series of protocols and operational guidance for responding to public health emergencies have been released successively. The system of command in response to public health emergencies at the national, provincial, and local levels has developed in an orderly manner with measures in place to support decision-making while referring to video consultations, commands and coordination, information exchanges, emergency on-duty procedures, resource management, and dispatch procedures [11].

Second, the capabilities for surveillance and early warning systems to detect public health emergencies have continued to increase. China has initiated the largest direct-reporting network for major infectious diseases and public health emergencies in the world, and the average reporting time has been reduced from five days to four hours. Surveillance information from relevant platforms has been further integrated, and an institutionalized evaluation mechanism on the risks of public health emergencies has been put into place. These information systems have been applied on a large scale in COVID-19 information management, information visualization, modeling of transmission, trend prediction, and analysis, ensuring comprehensive and automated management and services [12].

Third, competence in devising on-site health emergency responses and guaranteeing the provision of supplies has been enhanced. Since 2010, China has deployed 58 national public health emergency response teams in four categories, established a reserve system for national public health emergency supplies, and developed a mechanism to coordinate and dispatch supplies. These efforts have proven to be significantly helpful in coping with several major emergencies. For example, China dispatched its emergency rescue team to support efforts to combat Ebola in West Africa in 2014 and conducted a rescue campaign after an 8.1-M earthquake in Nepal, doing its part to assist in consolidating a line of defense for protecting public health worldwide.

4.2 Shortcomings

First, as the application of IT in decision-making and preparedness efforts for disease prevention and control is still limited, technologies that can detect new infectious diseases and abnormal cases in a timely manner are in short supply, as is the technological competence to collect, integrate, and analyze information from multiple channels. A case-in-point is the current early warning system against infectious diseases that was built and put into service in 2008. Its platform structure, data management, and modeling have been in place for over 10 years without the effective application of AI, big data, or algorithm-based identification.

Second, the information sources for surveillance and early warning systems must be diversified, and the sharing mechanism needs to be improved [13]. The existing surveillance and early warning systems mainly depend on reports of confirmed cases in medical facilities whose data and content are too simple to provide key information—such as symptoms, contact history, and travel history—to support surveillance and early warning systems. The collaboration between medical treatment and disease prevention should be further strengthened, although the early warning system is lagging. An effective information-sharing mechanism has not yet been built within the health system or between sectors and agencies. Moreover, there is a labor shortage in facilities for disease prevention and control. Institutions that provide medical treatment and disease prevention are generally under fragmented management [14], leading to more acute issues, such as low efficiency in information collection and analysis, inappropriate health services, and lack of timeliness.

Third, shortcomings remain in the IT infrastructure, and the ability to collect and integrate information must be strengthened. The absence of information interaction between multiple emergency management systems [15] is compounded by fragmentation and information barriers between the relevant authorities. Decentralized emergency data are difficult to collect at agricultural and animal institutions. Isolated platforms and inconsistent environmental information standards result in a hodgepodge of data forms and standards for various authorities. Without a uniform reference system, obstacles prevent the cross-department retrieval, integration, and sharing of emergency-related big data. Outside of medical treatment establishments, there are many other channels for collecting health-related information, mostly via manual retrieval, which has low efficiency. International information can only be shared through passive reporting or notifications by international organizations or institutions, making it difficult to access complete and integrated emergency information in a timely manner.

5 Targets and tasks for the development of smart emergency responses in China

5.1 Development targets

By 2025, a new generation of IT will be widely applied in health emergency management to put into place and implement a preliminary intelligent public health emergency response system that features integrated resources, application of intelligent technologies, mutual efforts and benefit-sharing, overall awareness, science-fueled efficiency, fast and agile responses, coordination and interconnection, and highly efficient dispatch procedures. That is, the capabilities for responding to emergencies, focusing energy on core areas, and guaranteeing the availability of emergency supplies will be enhanced. The emergency rescue team and system for providing materials and equipment should be improved. Competence related to early prevention, timely discovery, rapid responses, and effective resolution of issues will also reflect significant progress and become aligned with international standards. All efforts will be made to prevent and mitigate the outbreak and spread of emergent infectious diseases in China to the greatest extent possible.

By 2035, a modern intelligent response system for public health emergencies will be well-established and will enable the authorities to effectively address the risks and challenges generated by public health incidents. This is in line with the requirements of a moderately prosperous society in all respects, and it will be highly coordinated and combined with a new generation of IT to promote social participation. A global intelligent surveillance and early warning mechanism triggered by multiple points, which will cover all types of hazards, factors, and processes, will be erected; thus, a modern smart system for decision-making and responses to health emergencies will be implemented. Continued efforts will be devoted to improving emergency management, facilitating core emergency rescue efforts, providing overall guarantees in emergencies, and promoting social coordination. The capabilities for handling overseas emergencies will be at the same level as in developed countries, and a 3D system consisting of land, sea, and air efforts for medical treatment and rescue missions in emergency situations will take shape.

5.2 Major tasks

5.2.1 An intelligent platform for infectious disease surveillance and early warnings triggered by multiple points based on AI data and technology

Based on China's mechanical advantages in the joint prevention and control of infectious diseases, data barriers between administrators and executing agencies will be removed. Big data, 5G, the blockchain, cloud computing, and AI will be coordinated to establish a mechanism to share multi-variant data and implement a modern intelligent surveillance and early warning system triggered by multiple data points. Information on public health emergencies will be automatically collected from various monitoring spots and channels for integration, governance, visualization, detection, and analysis to make early judgments on risks or nascent signs of impending issues. Subsequently, warnings will be automatically disseminated, and science-based prevention and decision-making processes will

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underpin such efforts.

First, proactive surveillance and investigation technologies should be improved to improve data quality and access efficiency in multisource surveillance processes. Key provinces and areas will be selected to establish a proactive surveillance system for symptom complexes, deploy smart software for the surveillance and detection of infectious diseases, and automatically retrieve information (without relying on diagnosis information) in suspicious cases with symptoms pointing to infectious diseases from the information systems of hospitals. This will proactively capture key information for the purpose of providing early warnings against infectious diseases in a timely manner with reference to rules and machine-learning models. In this way, warnings can be issued early without disrupting diagnostic or treatment processes or increasing the workload of clinicians. The data will be encrypted for better management. A big-data surveillance and early warning system for protecting public health and a database that supports intelligent warnings need to be established to dynamically and quickly display changes in trends as time progresses and spatial distribution characteristics for data coming from multi-source surveillance.

Second, it is important to enhance research on the prediction and early warning signs of infectious diseases and select the proper smart algorithms for this purpose. Highly efficient and science-based detection algorithms hold the key to providing early warnings. As big-data-based multichannel surveillance is deeply intertwined with public health incidents, there are many data sources that can be used for providing predictions and early warnings. However, the effectiveness of early warning methods and the precision of warning results must be held to high standards. By examining the research on machine learning, deep learning, non-surveillance learning, and other AI algorithms, it will be possible to realize the creation of an intelligent early warning system triggered by multiple points. Given the complex and ever-changing nature of issuing early warnings against infectious diseases, dynamic corrections (adjustments) should be performed to improve the parameters for models in practice and to balance agility and specificity in providing early warnings. Measured against fitness for local conditions, intelligent models of predictions and warnings will be screened and selected, which will jump-start a process of running, evaluating, and improving models.

5.2.2 A whole-process intelligent command platform for emergency responses that connects people, machines, and materials

Based on overall awareness, integrated communication, public safety and security, and other key technologies, a smart command system for providing emergency responses must be erected; it will feature agile responses, coordination and interconnection, and highly efficient dispatch mechanisms. After all elements in the process for public health emergency preparedness, resolution, and responses are determined, situations involving public health incidents will be aggregated for presentation, realizing whole-process management encompassing the reception of incident reports, emergent responses, command and dispatch actions, analysis and judgement, coordination and consultation, and emergency appraisals. This will provide IT with support to underpin the intelligence, evenness, and integration of emergency responses and commands.

First, we will construct an intelligent command platform to respond to public health emergencies (emergency response centers). Based on a new generation of communication, AI, drones, satellite positioning, and other technologies, a command system for public health emergencies and a remote-coordination system will be developed to guarantee the efficient and smooth operation of emergency campaigns in all sorts of areas (disease-plagued areas, remote areas, etc.). The command headquarters will be positioned at the front and connected and aligned in a timely manner with the backstage command center.

Next, the foundation for digital infrastructure will be solidified and a smart platform to dispatch personnel and materials in response to public health emergencies will be built to ensure fast responses during the command process when an emergency occurs. Prearrangement plans at all levels and in all categories will be recorded in an e-archive and managed based on a classification system to enable the whole process to be conducted online, including the approval of prearrangement plans, recording data, and revisions.

Furthermore, perspective networks and data sources should be combined. The perspective network will be deployed, and cross-departmental data sharing, which will include social and Internet data, will be integrated to capture surveillance information of all sorts in a timely manner, out of which will come a dynamic awareness of incidents' scale, on-site situations, and medical resources. The collection of data for the perspective network will depend on emergency, public, and low-power-dissipation wide-area networks. The capabilities related to perspective networks and transmission layers should be enhanced when devising a perspective network for public health emergencies.

5.2.3 A System in support of smart decision-making

Based on informatization and data foundation in the current health emergency management system, the analysis and mining of big data and AI-assisted analysis could be combined to establish an overall model to clarify event and prearrangement chains. Then, a comprehensive judgement on public health emergencies could be produced, and decisions could optimized with the help of feedback from a closed loop. Beginning with public health emergency management, multiple layers could be added and integrated to display surveillance and perspective data and retrieve spatial information. Dynamic awareness of incidents' scale, on-site situations, medical resources, and other issues could be obtained to govern, manage, and visualize big data from multiple sources. Considering the features of public health emergencies, functions including judgement on special topics, production of smart solutions, and visualization of special assistance with decision-making, along with summaries and appraisals, could be introduced to support science-based decision-making processes.

First, emergency management functions based on geographic information systems should be improved and aligned with the geographic information public service platform "Digital Government" with standards and norms being formulated with the aim of realizing various functions and providing services related to layers, path planning, development of relevance analyses, data visualization, and integrated inquiry.

Second, smart analysis should be applied to elaborate on the dynamics of public health emergencies. Models based on research will be built, and 3D visual simulations for key areas will be developed to simulate the development trends of public health emergencies, evolution of transmission chains, and their impact. Thus, evaluations could be conducted on a scale potentially subject to various influences, casualties, and economic losses.

Third, an application system for a comprehensive risk assessment will be built. Application research on risk assessment based on the region, length of time (year, quarter, or month), and relevant topics could be used to help develop models to display information and conduct analysis. After an incident is reported, it is automatically matched and entered into the system for carrying out a judgment procedure. A knowledge model to assist in decision-making processes in public health emergencies would help officials analyze and clarify the characteristics of incidents' occurrence and evolution, along with the difficulties in addressing all types of public health incidents through automatic and systematic production or artificial interventions. Proposals will be made for risk prevention, emergency disposal, rescue, and relocation.

5.2.4 An Application platform based on the IoT to guarantee provision of materials in emergencies

Based on these studies, an application platform to guarantee the provision of materials in public health emergencies featuring uniform instructions, coordination efforts, and orderliness, as well as efficient operation, will be put into place, and a centralized mechanism to share reserve supplies in emergencies will be improved as a network securing emergency supplies with comprehensive coverage is rolled out. In the case of emergencies, the supply-dispatching mechanism is triggered based on actual demand and breaks geographic and hierarchical boundaries according to the principle of prioritizing proximity and speed. The mechanism will connect the upper and lower layers of the hierarchy to form a coordinated, even dispatch structure for rapidly mobilizing materials to support disaster relief and mitigation campaigns. Radio frequency identification based on the IoT will be adopted in the establishment of smart material storage systems for emergencies. In normal times, the management, maintenance, inquiries into, and collection of statistics regarding all sorts of resources should be prioritized; however, in emergencies, the dispatch and distribution of resources should be emphasized. Information-based approaches should be utilized to realize the efficient monitoring of the distribution and delivery of emergency materials.

6 Countermeasures and recommendations

6.1 Planning and execution of major projects for national comprehensive biological surveillance and provision of early warnings in health emergencies

An integrated platform for carrying out global biological surveillance and providing early warnings will be planned and built; it will consist of a whole-process information surveillance system with global coverage of public health and bio-security issues to support the coordination of multiple sectors and utilize resources from multiple channels while considering all factors for all types of hazards. As it will promote the cross-sector sharing of core information; it will also aim to boost the timeliness and fidelity of emergency surveillance to issue warnings in a timely manner. Risk evaluation involves multiple stakeholders and disciplines to ensure the early identification of potential threats related to public health incidents, which also provides science-based support for precise decision-making and implementation.

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Top-level design efforts will be carried out to produce a smart emergency response system with a consistent philosophy whose functions are coordinated within a unified structure for ensuring resource-sharing. The components of this system will also be standardized. This design, linked to the national CDC, will be planned in a centralized manner at the national level, constructed at the sub-national level, and deployed and applied at the local level in cities, counties, and districts. The overall framework will be devised while considering the entire picture of the relevant systems. Special plans will be made for staffing related to the payroll system, industrial development, and technological innovation to form a planning system with full coverage and multi-layered management. This system will follow category-specific guidance and connect multiple plans. Businesses will be interconnected, and data will be synchronized with the IT systems of the public security and emergency management departments. Implementation plans will be rolled out according to the responsible division, with the targets broken down and tasks prioritized.

6.2 Revision of laws and regulations regarding smart preparedness for health emergencies

The application of intelligent technologies and instruments may trigger legal or regulatory issues related to bio-security, data safety, privacy, and public health information. In major or severe emergencies, for the purpose of ensuring social stability and national security, administrative commands and ad hoc rules may be implemented to impose restrictions on the measures of and approaches to smart emergency responses while ensuring security. A case-in-point is the on-site epidemiological survey of COVID-19, when accompaniment by staff from the public security department is required so that personal travel traces, close contacts, and personal health information can be acquired. To tap into the potential of smart emergency responses, it is recommended that officials prioritize bio-security, data safety, privacy, and public health information in the operation of smart emergency systems while improving and revising emergency laws and regulations. Thus, sufficient legal guarantees of smart emergency preparedness can be ensured.

6.3 Maintenance of smooth data-sharing and the sustainability of emergency management mechanisms

Drawing on a new generation of IT, we will focus on information integration and interconnected development with various sectors of public security, customs, geology and meteorology, ecology, transport, and information communication to support the integrated and homogeneous development of new technologies for smart preparedness and secure the fusion of all kinds of business, data, and technologies. Thus, coordinated management and services across multiple layers, regions, systems, sectors, and businesses can be realized. It is recommended to construct a top-level design for a smart emergency response system at the governmental level and introduce coordinated planning and rational deployment with great efficiency to ensure orderly progress. Data-based platforms should be put into place for smart medical treatment, disease control, and healthcare. Cross-departmental and cross-regional infrastructure, characterized by efficient interconnection and the safe sharing of data, will serve as a mechanism to ensure intelligent emergency preparedness.

6.4 Development of industries related to smart preparedness for health emergencies

To address urgent needs concerning preparation, surveillance, early warning systems, command procedures, and assistance with decision-making, a smart response system will be constructed, and integrated development will be accelerated to provide society and the relevant sectors with personalized, diversified, and high-quality public services, supporting the rapid and efficient development of related industries. Deployment will be reinforced by cutting-edge fundamental theories, key and pillar technologies, and fundamental platforms of similarities to deeply integrate a new generation of IT and related industries, producing new economic forms driven by data and featuring man-machine coordination, cross-border fusion, joint contributions, and benefits for all. Customized services that meet individual requirements will be promoted to create and share valuable knowledge for health emergency responses. Investment and financing models will be innovated to attract private capital to a smart ecosystem of emergency preparedness, revitalizing, and maintaining social vitality in the pursuit of innovation.

6.5 Integration of clinical treatment and disease prevention

It is recommended that attention be paid to the gap between clinical treatment and public health by inserting concepts of public and population-based health into medical education and daily diagnosis and treatment [16], optimizing the management and practice of public health preparedness measures and integrating clinical treatment and disease prevention as quickly as possible so that medical practitioners can practice and promote a healthy lifestyle among members of society. Therefore, the importance of human resources should be reinforced for the promotion of public health. Public health management agencies should raise awareness of the importance of the applications of IT to better utilize it to address issues in public health emergencies. Versatile, talented people specializing in managing and building high-quality teams should be cultivated in the emergency response sector to combine public health emergency responses, the Internet, and IT-based approaches. Professional research institutions are encouraged to work with universities and colleges, and overall training bases for devising smart responses to emergencies must be constructed, as they will provide a capable pool of experts at the national level, reflecting an effort to aggregate sources of wisdom and overcome barriers in emergency preparedness.

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