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Development Strategy of Smart Emergency Response Technology for Disasters and Accidents by 2035

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Abstract: The development of smart emergency-response technology for natural disasters and accidents is an important part of public safety. It is also vital for China to improve its national governance and safety level. This study aimed to clarify the long-term goals of developing smart emergency-response technology by 2035 and provide support for the systematic planning and forward-looking deployment of a smart emergency-response strategy in China. Considering China's development needs, this study analyzed the international situation and main development trends of smart emergency-response technology for disasters and accidents. Subsequently, it analyzed the current status and problems of China's development from the perspectives of natural disaster prevention, accident prevention, and emergency platform construction. Further, considering the development of new-generation information technology, we proposed an overall framework and strategic direction for developing smart emergency-response technology in China, including important directions for technological development, key basic research directions, and tasks for major scientific and technological research and development. Furthermore, we proposed corresponding suggestions from the perspectives of policy and theoretical systems research.

Keywords: natural disaster; accident; smart emergency-response technology; information technology enabling

1 Introduction

Disasters and accidents occur frequently in China. Natural disasters generally have characteristics of a wide range of types, a wide area of impact, and heavy disaster losses. According to the statistics of the National Bureau of Statistics of China, in the past 10 years [1], the average annual disaster-affected population was approximately 2.5×10^8, the average annual deaths from disasters were approximately 1800, the average annual direct economic loss was approximately 380 billion CNY, and the annual average total area of forest fires was 4.85×10^4 hm^2. This indicates that the overall situation of accidents and disasters had improved but was still severe. In 2019, there were 29 519 deaths from various production safety accidents, including 1.474 deaths per 100 000 people in industrial, mining, and commercial enterprises; 0.083 deaths per 10^6 tons in coal mines; and 1.8 deaths per 10 000 vehicles in road traffic [2]. Comprehensively improving emergency-response capabilities, building a comprehensive and three-dimensional public safety network, and building a higher-level safe country are major requirements for national development [3].

With the development of new information technology, intelligent development of emergency disaster response has become an international trend. Building of an intelligent and multilevel protection system for public security has become a major national strategic need, as it can provide precise guarantees for national stability, sustainable social development, protection for residents' lives, and property safety [4]. Strengthening technological support is the core

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driving force to improve emergency management capabilities and refinement levels in the entire process of risk prevention, monitoring and early warning, disposal, rescue, recovery, and reconstruction [5].

The development of new-generation information technologies such as the Internet, Internet of Things, fifth-generation mobile communication technology, cloud computing, big data, and artificial intelligence have brought innovation opportunities to emergency management [6]. Facing the goal of comprehensively improving national capabilities for emergency management, exploring a development strategy for smart emergency technology that meets the needs of the country's economic and social development is a major and urgent historical mission. This study thus focuses on the development of an intelligent emergency-response technology for disasters and accidents that is demand-oriented, and based on the international situation and main development trends; focuses on the development status and problems in the field of disaster accidents in China; and explores the strategic ideological framework and direction tasks of smart emergency development to address the long-term goal of 2035.

2 Demand analysis for the development of smart emergency technology for disaster accidents

2.1 Natural disaster prevention

As urbanization accelerates, the overlap of population, wealth, productivity, and areas prone to major natural disasters has increased, and the public's risk of catastrophic disasters has risen. In recent years, the world has entered a geologically active period. Earthquakes tend to occur frequently worldwide, and many earthquakes of different magnitudes have occurred in China. Supertyphoons caused by climate change pose a serious threat to urban agglomerations in the eastern coastal area. Most urban agglomerations the country has built or is planning to construct face threats such as earthquakes of magnitude 7 or higher, strong typhoons, floods in the river basin, and giant landslides and mudslides. Earthquakes, typhoons, rainstorms, floods, droughts, geological disasters, and forest fires are major natural disasters in China, and catastrophe response has become an urgent and national strategic need.

For the risk assessment of major natural disasters, monitoring and early warning—especially the early warning capabilities for short-term extreme disasters—as well as medium- and long-term prediction technologies need to be improved. Moreover, technologies such as monitoring and early warning, prediction and forecasting, emergency preparedness, and rescue for major disasters in large cities and urban agglomerations need to be developed. Further, many key types of equipment still rely on imports. With the acceleration of urbanization, secondary disasters caused by natural disasters have become more serious, and monitoring and early warning technologies for major disasters, such as barrier lakes, dam breaks, and dyke bursts, still need to be the focus of research and development.

2.2 Accident and disaster prevention

Facing industrial transformation and fiercer international competition, safety production pressure is huge in China. Because of the country's economic development, there was high demand for energy and raw materials, the mining depth increased, large-scale chemical parks increased, urban networks of underground pipes were densely constructed, and production safety faced severe challenges. The possible coupling of multiple disasters increases the complexity of disaster prevention. Occupational health problems in the production process became more prominent. Moreover, the numbers of occupational hazards in China, new cases of occupational disease, cumulative cases, and deaths all ranked first in the world, and are becoming increasingly serious. As safety issues related to nuclear radiation are prominent and its potential hazards and social influence are huge, nuclear panic could easily spread among people. Thus, technology for rapid detection of the dosage, type, and time of nuclear radiation accidents as well as technology for psychological intervention for the public at different stages of the accident are urgent research topics.

High-level manufacturing tends to be intelligent, and the popularity of green manufacturing, clean production, and circular production in the manufacturing industry has gradually increased. Major industrial equipment are developing in the direction of super-large size, high parameters, and harsh working conditions. Therefore, comprehensive and targeted promotion of the development of key technologies for safety assurance of major industrial equipment is a necessary condition for ensuring the safety and reliability of equipment, as well as realizing long-term operation and full-life safety management.

2.3 Emergency platform construction

Further improving the digital, intelligence, and integrated level of the technology for national emergency platform

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will enhance the response and its efficiency in emergencies. In particular, it is necessary to improve the ability of data acquisition and rapid analysis during emergencies based on the new generation of information technology, build the rapid response capabilities of emergency platforms at all levels, develop scientific prediction and assessment capabilities for emergencies and their response, and improve the decision-making and command capabilities of the emergency platform system.

3 Development status of smart emergency technology for disaster accidents

3.1 International situation

The new generation of information technology has been applied in natural and accident disasters for risk assessment and prevention, monitoring, forecasting and early warning, emergency response and rescue, comprehensive security, and other links. Through the empowerment of information technology, various links of emergency response were connected and integrated, and the levels of intelligence and precision in emergency response to various disasters and accidents were comprehensively improved. Globally, there have been many cases of smart emergency response to natural disasters and accidents. The United States, Europe, Japan, and other developed countries are actively developing smart emergency responses (Table 1) [7].

Accurate natural disaster perception based on information technology is a hot topic in the development of smart emergency response. For example, the United States has developed a series of mature products, such as the National Risk Index, Seismic Rehabilitation Cost Estimator, Hazus program of the Federal Emergency Administration of the United States that is used for disaster assessment and management, Advanced National Seismic System, and the National Earthquake Disaster Map. The Japan Earthquake Research Council has implemented projects such as the production of national earthquake risk maps.

The construction of emergency facilities and system capacity building for multi-hazard integration has been highly valued by countries worldwide. Supported by the National Science Foundation and based on the Natural Disaster Engineering Research Infrastructure Network, the Computational Modeling and Simulation Center [8] and the tornado hazard map developed by the National Institute of Standards and Technology, etc., have provided strong support for the construction of the United States' capabilities for comprehensive emergency response [9]. Based on the "Resilient Japan" strategy, Japan focused on promoting technological innovations for prevention and mitigation of disasters, especially earthquakes, tsunamis, meteorological disasters, and possible secondary accidents; they gradually established a complete system for disaster prevention and emergency that could monitor operations around the clock, collected and released environmental information, and conducted disaster assessments. The earthquake early warning system introduced by East Japan Railway to prevent major accidents during an earthquake, the submarine earthquake and tsunami observation network constructed and operated by the National Research Institute of Earth Science and Disaster Prevention, and the Dual-Frequency Precipitation Radar developed by the Japan Aerospace Exploration Agency were used to improve weather models [10]; they were also representative applications of technology.

Based on the empowerment of information technology, efficient cooperation between different regions, levels, and departments became possible, such as the Resilience Direct and Central Alerting System [12] of the Civil Contingencies Secretariat [11], and the "112" emergency linkage system covering all European Union member states.

The application of big data and big computing has become a trend. Based on data sharing, European countries have established multiple high-performance computing systems and applied them to the fields of climate, weather, and emergency response. These systems have achieved the goal of accurate analyses of natural disasters and accidents through large-scale simulations. The combination of emergency systems with disaster detection systems, navigation systems, and information technologies has improved the efficiency and level of emergency response, and they have been used widely internationally.

Various perceptual monitoring and data collection technologies continue to merge, and various quantitative modeling methods based on artificial intelligence, big data technologies, and high-end professional software continue to be combined. For natural and accident disasters, the capabilities of risk identification, early warning, information sharing, remote response, coordinated rescue, and comprehensive support have continuously improved. These characteristics have become a frontier trend in the development of smart emergency responses to global disaster accidents.

3.2 Main development trend

The development of information technology has brought new tasks and opportunities to smart emergency response. The main focus of information technology is to empower the development of a smart emergency response, mainly manifested in the following aspects [13].

Table 1. Examples of international intelligent emergency application systems.

	Related institutions	Typical examples
United Nations (UN)	Caribbean Catastrophe Risk Insurance Facility	Develop and strengthen the informatization of the knowledge base for key natural disaster risks. Conduct regional studies on the economics of climate change and the impact of natural disasters on specific sectors such as tourism.
	UN Economic Commission for Latin America and the Caribbean	Develop decision-making tools to help mitigate the impact of natural disasters. Improve climate data and information systems to support contingency planning and achieve wider disaster resilience [14].
	UN University - Institute for Environment and Human Security	The InsuRisk Assessment Tool compares climate and disaster risk with a short-term response capacity [15].
United States	Federal Emergency Administration of the United States	National Risk Index Seismic Rehabilitation Cost Estimator Hazus loss estimation software
	United States Geological Survey	Advanced National Seismic System
	National Science Foundation	Natural Hazards Engineering Research Infrastructure
	National Institute of Standards and Technology	Tornado hazard map
European Union (EU)	EU member states	Use the “112” emergency linkage system. Establish several high-performance computer systems for climate and weather fields to improve the ability of natural disaster prevention and control. The I-REACT project integrates the existing services in Europe into one platform to support the whole emergency management cycle and achieve the collaborative goal of integrating emergency response, disaster detection, and navigation satellite subsystems.
United Kingdom	Civil Contingencies Secretariat	Resilience Direct
	Medicines and Healthcare Products Regulatory Agency	
	Chief medical officer of the Ministry of Health and National Patient Safety Agency	Central alerting system
Japan	Headquarters of Earthquake Investigation and Research Promotion Earthquake Research Council	Map-making project for national earthquake risk
	Hyogo Disaster Prevention Center	Phoenix Disaster Management System
	East Japan Railway	Earthquake Early Warning System for the Shinkansen
	National Research Institute for Earth Science and Disaster Prevention	Seafloor Observation Network for Earthquakes and Tsunami
	Japan Aerospace Exploration Agency	Dual-frequency precipitation radar

3.2.1 Identification and assessment of unconventional and unknown risks

Facing the innovative development of new materials, processes, and technologies, one can build methods for risk identification and assessment as well as technical systems based on technologies such as the Internet of Things, big data, cloud computing, artificial intelligence, simulation, and scenario deduction. Considering the potential unknown risks arising from the collision and integration of industrial planning, design, technology promotion, etc., with the environment and society, intelligent identification and prediction technologies should be developed for precursor events to form a comprehensive control capability for unconventional and unknown risks.

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3.2.2 Intelligent linkage between active perception and predictive warning

The new generation of information technology provides a means for intelligent and active perception. The intelligent linkage of effective perception and prediction/early warning combined with the Internet of Things, data analysis, and intelligent computing is the development trend of intelligent emergency response in the future.

3.2.3 Multiple coordination and systematic emergency response

The development of information technology further realizes government–society–public collaboration and systemic intelligent emergency management to ensure close individual–community–city–provincial–international collaboration. This breaks through the traditional single-line model and the vertical connection of the original emergency participants.

3.2.4 Industry-wide integration, high sharing, and in-depth application of smart emergency response

Demand-oriented smart emergency development will inevitably promote the opening of data barriers between departments and industries. Integration of industry resources such as meteorology, environment, fire protection, medical treatment, construction, transportation, electric power, water conservancy, communications, and people’s livelihood can help realize diversified, intelligent, and integrated information acquisition and sharing, as well as promote the development of a smart emergency response to multi-industry integration, high sharing, and deep application.

4 Status quo of the development of smart emergency response to disasters and accidents in China

4.1 Basic situation

Scientific and systematic research has been continuously strengthened and applied to key links, such as monitoring and early warning, risk assessment, emergency rescue, restoration, and reconstruction of disasters and accidents in China. The emphasis on informatization and information technology in all links has significantly improved the capabilities of national disaster prevention, mitigation, and safety supervision.

4.1.1 Meteorological disaster forecast

A comprehensive typhoon monitoring system based on weather satellites, Doppler weather radars, and automatic weather stations has been developed, and its capabilities have reached the global advanced level. The model for regional typhoon air–sea coupling, which considered the effects of waves, ocean droplets, and tides, achieved a breakthrough in key technologies for typhoon numerical prediction. Moreover, the application of various technologies, such as typhoon initialization and physical process parameterization, significantly improved the level of typhoon track forecasting and increased the international influence of typhoon numerical forecasts. The typhoon business platform covers typhoon path display and retrieval, forecast production, early warning information release, and other functional modules and provides various high-precision functions—such as the typhoon path, intensity, and ensemble forecasts—for the National Meteorological Center, East China Regional Meteorological Center, South China Regional Meteorological Center, and other units. These products have provided an important basis for typhoon prevention and emergency decision-making in coastal areas and have played an active role in reducing the loss from meteorological disasters.

4.1.2 Ensuring the safety of coal mining

Research on guarantee technology for coal-mining safety has entered the development stage of establishing safe mines and realizing comprehensive regional prevention and control in China. Comprehensive technologies such as for the prediction of gas disaster-prone areas, evaluation of high-efficiency gas drainage and drainage effect, and gas disaster monitoring and early warning have been developed. A technology system for gas disaster prevention and control consisting of basic theory, process technology, instrumentation, and special equipment has been gradually formed. The technology for rapid measurement of coal mine gas content has solved the problems of accelerated gas desorption, lack of sampling in soft coal seams, excessive sampling time, and large loss estimation errors. This technology provides the basis for gas management.

Breakthroughs in technologies—such as the Ethernet ring network + Fieldbus, broadband access equipment, large-capacity intrinsically safe power equipment, and abnormal linkage control—that were adapted to underground explosive environments supported the development of an early warning platform that included geological surveys, production technology, ventilation safety, office automation, digital mining, and safety production monitoring. These breakthroughs also realized the hidden-danger linkage control and dynamic early warning. In the mines, a wireless communication system for disaster relief using wireless transmission and wireless relay technology realized the real-time transmission of images, voices, and environments between the command base and the site, and it established a mobile rescue command system for mine disaster emergencies.

4.1.3 National emergency-response platform system

The first-generation national emergency platform system was established in China and has been widely used by the State Council, various provinces, municipalities, departments, and enterprises. The multi-factor, coupling event chain and plan chain construction methods were proposed, and a comprehensive forecast and early warning model based on the event chains was established. The functions of the key nodes of the national emergency platform system that met the requirements of the combination of peace were identified. Application software and database systems configured by the state, local governments at all levels, multiple departments, and large enterprises have been developed. A collaborative consultation system was established that was cross-domain, cross-level, cross-time, and cross-regional to provide an “emergency picture.” In response to the difficulty in obtaining information on the “last 10 km” of the emergency site, a three-dimensional monitoring system and mobile emergency platform equipment were developed. The national emergency platform system was completed, and a standards system framework was formed. Key technical standards and specifications such as for the design and development of the emergency platform system, information exchange and sharing, and spatial and non-spatial information integration were formed. The automated and intelligent emergency management system provides advanced technical means for establishing an emergency-response mechanism that has unified command and is fully functional, responsive, and efficient, as well as for preventing and responding to various disasters and accidents.

4.2 Problems

Compared with the international mainstream level, smart emergency technology has made great progress in China. Some technologies have reached the advanced international level, but the overall level still needs to be strengthened.

In response to the problem of unclear risks of natural disasters and accidents, a national comprehensive risk survey of natural disasters was planned and carried out in China from 2020 to 2022. This study aimed to (1) clarify the risk factors, such as disaster factors, disaster-bearing carriers, and historical disasters; (2) comprehensively investigate and evaluate the capabilities of disaster prevention, mitigation, and relief in various regions; (3) objectively understand the comprehensive risk level of natural disasters in the country and various regions; and (4) provide a clear reference for the development of smart emergency response.

Moreover, there is insufficient data sharing. Large amounts of data—such as on land surveys and mapping, geological surveys, resource surveys, animal and plant distribution, disaster census, population movement, urban system operations, and industry safety production—were controlled and managed by different functional departments. Because of lack of the data’s timeliness, credibility, security, and sharing, the phenomenon of “information islands” has not been eliminated.

The risk analysis and evaluation system applied to cross-domains, multi-hazards, and the whole process were inadequate and far from meeting the actual needs of future economic and social development for the level of precision emergency management. Moreover, the lack of calculation and analysis tools for large-scale disasters, especially accurate calculation methods and tools for disaster assessment, could not meet the needs of smart emergency response in terms of the accuracy of relevant parameters.

5 Development direction of smart emergency technology in China

5.1 Development ideas

Smart emergency technology for disaster accidents must be developed to meet the need for a “safe China” that is based on the present and focused on the future. Development and security must be coordinated, science and technology must play a role, and advanced technologies’ transformation and comprehensive application must be strengthened. These measures provide support for the comprehensive improvement of the national governance system and modernization of governance capabilities.

Focusing on the active, comprehensive, and accurate monitoring of disasters; early prediction and rapid prediction of multi-hazards and cross-scale disasters; scientific decision-making across regions, levels, and departments; comprehensive coordination and efficient disposal; and other scientific issues, the aim of exploring the development path of smart emergency technology was to propose a forward-looking and overall strategic plan for developing

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smart emergency technology. With the 14th Five-Year Plan and the long-term goal for 2035, Fig. 1 shows the development strategy of smart emergency technology for disasters in China. The country should further improve the national emergency management system, play a leading role in scientific and technological innovation, and realize the transformation of emergency management from passive response to active support.

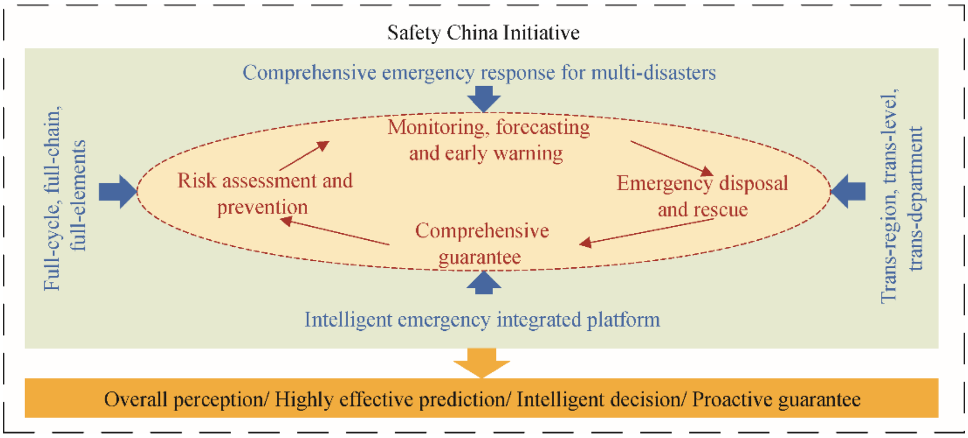

Fig. 1. Development strategy of the intelligent emergency technology for accidents and disasters.

5.2 Important direction of technological development

5.2.1 Quantitative risk assessment technology and system research in the whole cycle and whole chain

Focusing on the full cycle of disaster and the entire chain of emergency management, disaster mechanisms and assessment models were explored, and quantitative, standardized, systematic, and comprehensive risk assessment technologies were gradually realized. Some technologies such as for multi-hazard, multi-scale, multi-physical field, and systematic risk assessment; simulation of the multi-hazard coupling disaster-causing process; scenario construction; and risk assessment of “data-calculation-reasoning” fusion need to be developed.

5.2.2 Research and development of the forecast and early warning technology and system under multi-hazard coupling and multi-field collaboration

Natural disasters occur frequently and repeatedly in China. Thus, it is imperative to establish a network system for disaster monitoring that works in real-time and ensures multi-source information fusion; promote research and development on technology and systems for disaster evolution prediction; and build a composite and efficient early warning system with vertical and horizontal connectivity and full coverage. Under micro, ubiquitous, integrated, standardized, intelligent, automated, networked, and precise conditions, a smart monitoring and early warning system for disaster accidents can be established.

5.2.3 Emergency rescue technology and equipment across regions, levels, and departments

The development of remote, remote-controllable, and intelligent key technologies for emergency on-site handling and rescue, rapid evacuation and refuge, real-time transmission of multidimensional information, virtual simulation, automatic search and rescue of personnel, and human injury assessment need to be developed. Further, online emergency systems that deeply integrate man, machine, and things and some equipment such as emergency robots need to be developed. This would improve orderly coordination, automation of rescue, and intelligent control; develop disaster prevention, mitigation, and relief technologies; improve the public’s capabilities of self-rescue and mutual rescue; and achieve an intelligent and efficient emergency response.

5.2.4 Integrated intelligent emergency platform construction

Based on the new generation of information and public safety technology, such as the Internet of Things, cloud computing, big data, simulation, scenario deduction, virtual reality, and digital twins, a smart emergency platform including risk assessment and prevention, monitoring, forecasting and early warning, emergency response and rescue, and business continuity management would be built. A mechanism for cross-departmental and cross-regional information sharing should be constructed, and a new generation of emergency platform systems that covers regions from individual members of the public to building groups and communities, urban agglomerations, provinces, and countries will be constructed.

5.3 Key directions of basic research

5.3.1 Research on the disaster mechanism of major disasters and coupling of multiple disasters

Relevant basic research mainly included the theory of identification, monitoring, and early warning for major hazards; law of evolution of concurrent multi-hazards and secondary derivative disasters; and the risk assessment theory and calculation analysis methods for major disasters such as earthquakes, typhoons, and geological disasters.

5.3.2 Construction of a multi-factor coupling scenario and theoretical methods for scenario deduction

Related basic research mainly included construction methods for structured scenarios under the influence of natural, technical, and environmental factors, as well as methods for scenario deduction and situation assessment supported by big data analysis, high-performance computing, virtual reality, and artificial intelligence.

5.3.3 Change mechanism and method for evaluating the resilience of disaster-bearing carriers

Related basic research mainly included methods for analysis of the vulnerability and robustness of different types of disaster-bearing carriers, such as buildings, critical infrastructure, cities/urban agglomerations; fast and large-scale calculation analysis; and a comprehensive theory for structural safety evaluation under typical disaster loads of buildings. It also considered the evolution of rock and soil properties; interaction mechanism between rock, soil, and the structure; catastrophe mechanism of major infrastructure such as tunnels, underground caves, and pipelines under complex engineering environments such as high stress and explosions; and the theory on security interdependence and correlation effect evaluation for different major infrastructures.

5.3.4 Comprehensive method for integration and fusion analysis of multi-granularity information

Related basic research mainly included active early warning methods based on triggering of the data flow threshold; theory on crisis early warning based on the decision support model and expert system; comprehensive theories on prediction, early warning, analysis, and decision-making based on big data, cloud computing, Internet of Things, artificial intelligence, complex system modelling, and other technologies; and the accurate decision-making method based on the integration of data, model, and knowledge.

5.3.5 Methods for analyzing public opinion on disasters and accidents

Relevant basic research mainly included methods for fast collection and high-speed processing of big data on online public opinion, methods of public opinion identification and judgment, models on public opinion evaluation, and methods to distinguish between public opinion noise and false Internet information.

5.3.6 Method for disaster case reasoning based on data

Related basic research mainly included methods for rapid collection, digital storage, and analysis of disaster and accident case elements; quick case retrieval and adaptation; and digital case reasoning based on the dynamic demand of emergency decisions, data–model–case coupling reasoning, and situation prediction.

5.3.7 Emergency response, rescue technology, and equipment theory

Relevant basic research mainly included theories and methods for fast acquisition and high-speed transmission of on-site information; sky-air-ground integrated methods for intelligent perception, coordination, and scheduling; intelligent application methods for drones and robots for on-site rescue and command; the principle of active perception and natural interaction between humans and robots sharing environments; the principle of robot swarm intelligence; and the principle of modern intelligent rescue equipment.

5.3.8 Fusion analysis method for big data and big computing for complex disasters

Relevant basic research mainly included large-scale rapid analysis methods for hybrid data models of disaster evolution; multi-parameter and multi-dimensional matching of large-scale data on disaster process simulation and field data; dynamic correction method for the disaster evolution process, big data-based emergency awareness, and early warning theory; fast calculation methods for scenarios of large-scale complex disaster accidents based on high-performance computing; modeling theory for a man–machine interactive simulation; a method combining cloud computing and edge computing; and an integrated computing theory and method of ternary fusion of physical, information, and social spaces.

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5.4 Scientific and technological research tasks

5.4.1 Catastrophe monitoring and forecasting technology

The country should support the construction of an observation station network for earthquakes, geological disasters, short-term heavy precipitation, thunderstorms, gales, hail, tornadoes, and other strong convective weather conditions. The ability to monitor strong convective weather based on data from a Doppler weather radar needs to be improved, and fast four-dimensional technology for variational assimilation with minute-level observation data (ground automatic stations, radar, etc.) should be strengthened as the core. Based on the fusion technology of the rapid cycle forecast products using a mesoscale numerical model and high-resolution observation data, technology for rapid cycle forecasting of the movement (propagation), development, and extinction of strong convective weather systems should be constructed. Because of the unstable layer nodes, unstable dynamics, changing water vapor conditions, layer heights of different characteristics, and physical quantities with different characteristics under strong convective weather, a statistical analysis technology for discrimination should be developed. Further, probability prediction technology for gridded strong convection classification based on high-resolution numerical prediction of physical quantities' diagnostic characteristics should be constructed.

5.4.2 Risk assessment and prevention of mine accidents

The evolution law of mine accidents under the coupling of multiple fields and the mechanism of disasters must be studied. A closed-loop management system for mine accidents based on quantitative risk assessment needs to be constructed, and the information perception technology of “human, machine, environment” based on the mining environment needs to be studied. Real-time big data monitoring and early warning methods for major mine accidents must be proposed. The task direction was mine accident communication positioning and rapid intelligent search technology as well as development of top-drive vehicle-mounted drilling rigs with ground high-power and large-aperture, rescue drilling rigs suitable for complex underground environments and emergencies, and automatic disposal equipment in disaster areas.

5.4.3 Risk assessment and prevention of chemical and hazardous chemical accidents

The monitoring technology and equipment used in the entire process of petrochemical and hazardous chemical production, storage, use, and transportation need to be studied. Disaster source diagnosis, technology and equipment for accident early warning, and methods and technologies for accident control need to be developed. The prevention and control of accidents involving chemical and hazardous chemicals need to be realized. The task direction was to study the rapid detection technology of petrochemical and hazardous chemical accidents, technology for public safety hazard assessment from petrochemical and hazardous chemical leakage, and emergency-response technology, as well as to establish a comprehensive emergency rescue system. We need to establish a risk assessment and prevention system for oil and gas pipeline networks as well as lifeline engineering to substantially improve the safety level of the pipeline network and guarantee the safety of the supply. A unified management platform for oil and gas pipeline networks should be established to digitize in-service gas pipeline networks.

5.4.4 Quick acquisition of emergency information through transmission technology and equipment

Multi-functions, such as rescue and disaster relief, earthquake disasters, surveying and mapping applications, aerial dynamic investigation, security monitoring, and aerial photography, need to be studied. Fast acquisition and transmission of field information that is not restricted by altitude needs to be studied. The goal is to develop equipment for real-time collection and transmission of information, airdrops of small emergency rescue materials, information transmission relays in emergencies, and remote command coordination, such as light-duty special drones and special robots.

5.4.5 Technology for disaster accident prediction and early warning based on data and calculation

Combined with the construction of new infrastructure, in the process of integration and application of the Internet of Things technology, we need to increase the basic data resources for disaster accident prediction and early warning. We need to explore the construction of fusion methods for scientific data computing, realize intelligent prediction and automatic early warning, and form the ability to intelligently research and judge disasters and accidents, and then push the intelligent emergency system from the Internet of Things to Intelligent Connection. We need to study the prediction and early warning technology involving deep integration of man–machine–things as well as develop the technology for large-scale disaster accident prediction, system for situation judgment of “community–city–urban agglomeration” across scales, deduction and visualization system for disaster accident scenarios based on digital twins, and a knowledge map of natural disasters and accidents.

5.4.6 Key technologies and guarantee platforms for resilient cities

There is a need to research urban resilience assessment technology under multi-hazard conditions (earthquakes, typhoons, rainstorms, landslides, mudslides, fires, explosions, leakage of hazardous chemicals, etc.) and construct a comprehensive integrated system of data models for urban resilience analysis. Moreover, real-time, dynamic, interactive, and integrated information collection, transmission, and processing need to be realized. Further, a "multi-hazard–multi-scale–multi-system" impact assessment system for mega-city resilience and a comprehensive urban resilience guarantee platform must be built. The system includes technologies for tracking gas leakage sources and positioning, underground space safety evaluation, warning and prevention of urban area waterlogging, real-time monitoring and forecasting of urban traffic operations and dynamic control, and safety evaluation systems for urban buildings and important infrastructure.

5.4.7 Research and development of independent intellectual property software

Digital modeling, computing, and simulation technologies have been used widely as core technologies in the field of natural disasters and accidents. The analysis of various disasters and accidents requires specialized system software, but much-advanced software is restricted for sale in China, which limits the development of smart emergency response. Therefore, there is an urgent need to develop a smart emergency software system with independent intellectual property rights, which mainly includes software for earthquake source analysis and intensity calculation, major infrastructure risk assessment, accident reproduction simulation, safety analysis and evaluation for building structure, calculation of city-scale disaster accidents, analysis for urban traffic simulation and emergency evacuation optimization, weather monitoring, forecasting and early warning analysis, emergency rescue simulation for complex disaster scenarios, and emergency management and decision-making commands.

6 Suggestions for the development of smart emergency-response technology for natural disasters and accidents in China

6.1 Policy suggestions

It is important to develop smart emergency-response technology for natural disasters and accidents and incorporate it into the work of emergency management departments at all levels as the central task of the emergency management system and capacity modernization reform. This involves making full use of various resources, giving full play to industrial advantages, doing good work in the transformation and service of social development, making scientific and technological achievements, and promoting a higher level of emergency management from informatization to intelligence jointly. Further, there is a need to encourage forward-looking, basic, and original scientific research in the field of emergency management even further; increase public financial investment in the transformation and application of information technology for emergency management, while simultaneously increasing the scientific investment of local government and industry; and build a new pattern of smart emergency development supported by multi-investment and multiple disciplines.

In the intersecting field of information technology and emergency management, the country should establish a national key laboratory, a national engineering technology research center, and other scientific and technological support institutions; build a group of research bases that represent the national level; and aim for world-class research. For example, large-scale test bases can reproduce the coupling effect of disasters and accidents digitally and visually and reproduce the secondary derivative events and chain of events caused by the destruction of the disaster-bearing carrier. A testing and certification center should be built for intelligent emergency equipment, information systems, and other products. Aiming at the occurrence, development, response, and disposal of natural disasters and accidents, there is a need to build a thematic database, advanced display system, and comprehensive analysis platform to carry out dynamic simulation, scenario construction deduction, situation research and judgment, optimization decision-making, and command tracking.

Further, it is important to explore the establishment of a cross-departmental organizational mechanism that covers scientific and reasonable top-level design; grid linkage of grassroots cooperation; optimization of the organizational process; deepening of data sharing; breaking down of departmental barriers; effective connection of various plans of different time scales and physical and virtual spaces; and reflection of the hierarchical and systematic nature of technological breakthroughs. Full play needs to be given to the leading role of government departments for emergency management, basic role of the market in the allocation of scientific and technological resources, main

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role of enterprises in technological innovation, supporting and leading roles of national scientific research institutions, role of the new forces of universities and colleges, and the catalyzing service role of scientific and technological intermediary institutions. This will strengthen resource integration, ensure integrated sharing and efficient utilization, and establish an innovation mechanism of scientific and technological collaboration for emergency management engineering that combines the government, industry, education, research, and application.

Moreover, there is a need to actively introduce advanced international technology and development experience, as well as strengthen high-level scientific and technological exchanges and cooperation with foreign-related fields to improve international scientific and technological cooperation. Finally, there should be timely tracking and grasping of the development trend of the technology and equipment for global intelligent emergency engineering, as well as efforts to ensure Chinese smart emergency technology develops simultaneously with the world at an advanced level.

6.2 Theoretical system research suggestions

First, there is a need to build a new risk theory system. Driven by technological innovation and major public safety requirements and taking the implementation of the Belt and Road initiative as an opportunity, we will strive to build a multilevel, sustainable, and innovative risk management system. Further, the country should strengthen the identification and assessment of conventional and unknown risks, focus on prevention and control before and during the event, and realize the transformation of public safety from passive emergencies to active prevention and control. The development of new monitoring and early warning models; early warning and emergency linkage technology; equipment research and development; and the change from monitoring, forecasting, and early warning to the emergency linkage of active perception, active prevention, and early warning should be realized. China's intelligent manufacturing has led to the intelligent development of emergency platforms and equipment, and it has fully supported intelligent emergency response in the new era.

Second, there is a need to build a comprehensive, three-dimensional public safety net. Further, an all-around and three-dimensional public safety guarantee—which can correlate horizontally with various emergencies such as natural disasters, accident disasters, public health incidents, and social security incidents, as well as vertically cover areas from the country to provinces, cities, communities, and the public—should be realized. At the same time, the technical system of this guarantee should cover the key links between risk assessment and prevention, monitoring, forecasting and early warning, emergency response and rescue, and comprehensive protection of public safety. Finally, there is a need to promote the interconnection of important nodes, break through key technological innovations and key equipment research-and-development bottlenecks that support the construction of a safe China, and lay a solid technological foundation for the construction of a higher level of safe China.

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