Governance Dilemmas and Optimization Paths of Artificial Intelligence in Risk Early Warning for Emergencies

Zhiqiang Wen, Chunping Mo*

Tianjin Normal University, Tianjin, 300387, China
**Corresponding author:18812722837@163.com*

Abstract: *Against the backdrop of the deep overlap between the risk society and the digital society, emergencies present characteristics such as hidden causes, rapid evolution, cross-domain impacts, and compounded hazards. The traditional experience-based and hierarchical early warning model can hardly meet the needs of modern emergency governance. By leveraging advantages such as multi-source data fusion, algorithmic analysis, dynamic prediction, and targeted push, artificial intelligence provides significant technical support for risk early warning. However, in practice, it faces governance dilemmas including lagging institutional supply, imbalanced data governance, insufficient algorithm supervision, and poor multi-stakeholder coordination, with a structural tension existing between technological logic and governance logic. This paper systematically explains the application mechanism of artificial intelligence in risk early warning for emergencies, conducts a theoretical analysis of the practical dilemmas from four dimensions-institution, data, algorithm, and coordination-and, on this basis, proposes optimization paths featuring legalization, standardization, collaboration, and human-centeredness, aiming to provide theoretical support and practical reference for enhancing the intelligent early warning capability for emergencies, improving the risk pre-control system, and advancing the modernization of China ' s national emergency management system and capacity.*

Keywords: *artificial intelligence; emergencies; risk early warning; data governance; modernization of emergency management*

Introduction

Human society has entered a new stage characterized by the parallel development of high risks and high digitization. Various major emergencies present a trend of frequent, multiple, and high incidence, with shorter risk transmission chains, faster diffusion speeds, wider ranges of impact, and stronger chain reactions, posing continuously severe challenges to public safety and social stability. Traditional emergency early warning systems rely heavily on manual monitoring, hierarchical reporting, empirical judgment, and administrative directives, and they have inherent limitations in information acquisition, analytical efficiency, judgment accuracy, and response speed.[1] As a result, they can hardly achieve effective capture and accurate early warning of hidden, early-stage, and cross-boundary risks. Emergency management still faces, to a large extent, the structural dilemma of emphasizing response while neglecting prevention. With the comprehensive penetration of digital technologies into the field of public governance, a cluster of intelligent technologies represented by big data, artificial intelligence, the Internet of Things, and satellite remote sensing provides critical support for reshaping the risk early warning process and improving risk governance efficiency. It also drives the gradual transformation of emergency management from passive response to active prevention and from post-event handling to pre-event early warning.[2] By leveraging its outstanding advantages in data processing, model fitting, trend prediction, and anomaly identification, artificial intelligence enables global perception, deep integration, and intelligent analysis of multi-source heterogeneous data, demonstrating great application potential in areas such as natural disaster monitoring, public health early warning, accident disaster prevention, and social security risk identification.[3] However, technological empowerment does not automatically translate into governance effectiveness. The embedding of artificial intelligence into risk early warning for emergencies-a highly public, political, and systematic governance scenario-is not merely a technical application issue but also a governance restructuring issue involving power structures, institutional rules, stakeholder relationships, and value orientations. In current practice,

intelligent early warning systems commonly face practical difficulties such as unbreakable data barriers, insufficient supervision of algorithm black boxes, ambiguous responsibility boundaries, poor inter-departmental coordination, and weak social trust. The contradiction between technological advantages and governance shortcomings is becoming increasingly prominent. Against this background, systematically revealing the institutional, data, algorithmic, and coordination dilemmas faced by artificial intelligence in risk early warning, deeply analyzing their underlying causes, and proposing optimization paths featuring legalization, standardization, collaboration, and human-centeredness can provide decision-making references for governments at all levels to improve intelligent early warning system design, break down data and information barriers, strengthen algorithm safety supervision, and establish sound multi-stakeholder coordination mechanisms. Such efforts will help enhance the accuracy, timeliness, credibility, and coverage of risk early warning, move the prevention threshold of emergencies forward, effectively safeguard public security and social stability, and provide solid support for advancing the modernization of national governance.

2. The Application Logic of Artificial Intelligence in Risk Early Warning for Emergencies

2.1 Global Perception and Integration of Multi-Source Data

The foundational support of artificial intelligence in risk early warning for emergencies comes from the global perception and systematic integration of multi-source heterogeneous data. Supported by diverse carriers such as Internet of Things monitoring devices, social media platforms, government information systems, industry operation databases, and satellite remote sensing imagery, intelligent early warning systems can break through the limitations of traditional information collection channels, which are characterized by a single source, limited coverage, and low update frequency.[4] They enable all-weather, all-domain, and real-time capture of risk clues, including changes in the natural environment, infrastructure operation status, public opinion dynamics, public behavior signals, and abnormalities in public services. Through processes such as data standardization, desensitization, correlation fusion, and dynamic updating, the originally scattered, fragmented, unstructured, and low-usability pieces of information are transformed into continuous, complete, quantifiable, and modelable high-quality risk data streams, thereby providing a solid data foundation for the early identification of potential risks, the tracking of risk evolution trends, and the judgment of risk critical states. The maturation of data perception and integration mechanisms drives the transformation of risk early warning from a partial, passive, and lagging information acquisition model to a global, active, and real-time risk perception model.

2.2 Situation Assessment and Prediction Using Intelligent Algorithms

Algorithmic models serve as the core engine of artificial intelligence in risk early warning, undertaking critical functions such as risk identification, correlation analysis, trend projection, level assessment, and threshold determination. Relying on algorithmic tools including machine learning, deep learning, anomaly detection, and time series analysis, the intelligent system can deeply mine massive, high-dimensional, and dynamic data to identify implicit patterns, abnormal correlations, and mutation signals that are difficult for human experience to capture.[5] Compared with traditional early warning models that depend on expert experience and manual judgment, the algorithm-driven assessment model offers advantages such as high processing speed, wide coverage, strong consistency, and robust anti-interference capability, which can significantly shorten the early warning cycle, enhance risk identification sensitivity, and improve the stability of trend judgment. The algorithmic assessment function not only provides objective, quantifiable, and visual analytical tools for early warning work but also drives the transformation of risk early warning from an experience-based, vague, and post-event traditional model to a scientific, precise, and preemptive modern model.

2.3 Precise Output and Adaptation of Scenario-Based Early Warning

The ultimate effectiveness of artificial intelligence in risk early warning depends on the deep adaptation and precise alignment between the technological model and the types of emergencies, regional characteristics, governance levels, and response mechanisms. Different types of emergencies exhibit significant differences in their causal structures, evolution logics, scopes of impact, and handling methods. The artificial intelligence early warning system is not a general-purpose technological tool; instead, it requires scenario-based, differentiated, and finely tuned adjustments in

terms of data weights, model parameters, warning thresholds, information formats, and dissemination channels. Through the precise output of early warning by type, level, region, and population group, the highly specialized and technical assessment results can be transformed into authoritative, concise, understandable, and actionable early warning information, effectively improving the efficiency of government departments in rapid response and precise handling while enhancing the public's risk awareness and self-protection capabilities.[6] Scenario-based precise output represents a key link for artificial intelligence to move from technological feasibility to governance effectiveness, and it also serves as an important foundation for the standardized and normalized operation of intelligent early warning systems.

3. Current Governance Dilemmas of Artificial Intelligence in Risk Early Warning for Emergencies

3.1 The Institutional and Regulatory System Lags Behind Technological Application

The rapid practice of artificial intelligence in the field of risk early warning presents a prominent contradiction with the insufficient supply and slow updating of existing institutional rules, which has become a fundamental dilemma restricting its standardized and orderly development.[7] At present, China has not yet formed a specialized legal and institutional system for the application of artificial intelligence in emergency scenarios. Core aspects such as data sharing, algorithm filing, early warning issuance, responsibility determination, fault tolerance and correction, and privacy protection lack clear, unified, and operable rule guidance. Due to the vague boundaries of responsibility for early warning errors, unclear accountability mechanisms, and the lack of fault tolerance mechanisms, relevant departments and entities generally exhibit conservative tendencies, including reluctance to open data, unwillingness to boldly trial the technology, and fear of taking risks. At the same time, the design, testing, deployment, and iteration of algorithmic models lack an institutionalized regulatory process. Technical standards, evaluation criteria, and ethical guidelines are not unified, leading to uneven quality of intelligent early warning systems and irregular operation. The lag in institutional supply has kept artificial intelligence early warning in a state where practice precedes rules for a long time. Technological application lacks stable legal expectations and institutional guarantees, causing governance risks and operational hazards to accumulate continuously.

3.2 Double Imbalance in the Data Governance Structure

High-quality, full-dimensional, and tradable risk data serve as the core for achieving precise assessment by artificial intelligence early warning models, and comprehensive data governance directly determines the effectiveness boundary of intelligent early warning. Under the bureaucratic and fragmented governance structure, emergency-related data are scattered among different departments, different levels, different regions, and different market entities, and cross-departmental, cross-regional, and cross-system data sharing and business collaboration lack normalized, institutionalized, and legalized guarantees, leading to the long-standing phenomena of data barriers and information islands.[8] In addition to barriers at the circulation level, the quality management of the entire data life cycle also exhibits obvious shortcomings. Problems such as inconsistent data collection standards, untimely dynamic update and maintenance, non-standardized labeling systems, inadequate handling of missing values and outliers, and imbalanced distribution of positive and negative samples are widespread, which directly lower the training effect of algorithmic models and impose rigid constraints on the accuracy and reliability of risk early warning. The dual constraints of poor circulation and poor quality make it difficult for intelligent early warning systems to obtain sufficient, high-quality, continuous, and reliable data support. Consequently, such systems not only fail to fully release the application advantages of the technology itself but may even trigger secondary governance risks such as early warning distortion or failure due to data deviation.

3.3 Obvious Shortcomings in Algorithmic Governance Capability

The algorithmic model serves as the core hub for the intelligent early warning system to transform risk data into early warning signals. Its interpretability, reliability, and fairness not only determine the accuracy of the early warning results but also directly affect the credibility and publicness of emergency governance. Due to the high complexity, non-linearity, and specialization of the algorithmic model itself, an "algorithm black box" naturally forms that is difficult for the outside world to

penetrate. Government regulators, frontline emergency responders, and the general public cannot fully trace the generation logic, decision-making basis, and uncertainty boundaries of the early warning conclusions, which not only weakens the social acceptance of the early warning results but also creates significant obstacles for responsibility determination and process supervision. At the same time, during the training process, the algorithmic model is prone to incorporating issues such as training data bias, historical sample deviation, and design preferences, which may lead to insufficient identification of or excessive early warning for specific regions, specific groups, or specific types of risks, thereby undermining the fairness and publicness of risk governance.[9] In atypical, small-sample scenarios such as extreme weather, emerging infectious diseases, and sudden social security incidents, the stability, robustness, and adaptability of the algorithmic model are seriously insufficient, making it prone to problems such as missed judgments, misjudgments, and delayed judgments. The safety and controllability of algorithms need to be improved.

3.4 The Multi-Stakeholder Coordination Mechanism Operates Poorly

Artificial intelligence risk early warning is a systematic project involving multiple stakeholders, including governments, enterprises, research institutions, social organizations, and the public. The current collaborative governance system remains imperfect, and its overall effectiveness has not been fully realized. Within the government, cross-departmental and cross-regional coordination and command platforms are inadequate, leading to poor information flow, inconsistent release standards, and lagging joint responses, thus making it difficult to form a concerted early warning effort. At the level of government-enterprise relations, the channels, rights and responsibilities, incentives, and guarantee mechanisms for technology companies that possess core technologies, data resources, and platform capabilities to participate in emergency early warning remain unclear. Data cooperation, technical support, and emergency responses mostly rely on ad hoc coordination and lack stable institutional arrangements. At the level of government-society interaction, the channels for the public and social organizations to participate in risk identification, information feedback, early warning dissemination, and emergency response are limited, resulting in low social awareness, trust, and engagement with intelligent early warning. Overall, the current artificial intelligence early warning system still exhibits a government-centered unilateral promotion pattern, with unclear allocation of rights and responsibilities among multiple stakeholders, poor process integration, and mismatched incentives and constraints. As a result, the advantages of technology are difficult to effectively translate into systemic governance effectiveness.

4. Optimization Paths for Artificial Intelligence in Risk Early Warning for Emergencies

4.1 Accelerating Institutional Supply and Building a Legalized and Standardized Support System

Top-level institutional design should serve as the core driver, focusing on the application scenarios of artificial intelligence throughout the entire process of risk early warning for emergencies. The whole chain of intelligent early warning should be fully brought under the rule of law, and clear rights and responsibilities boundaries should be delineated for the safe and orderly application of the technology in the early warning field, while providing stable institutional expectations. Efforts should be accelerated to formulate special regulations and normative documents in the field of intelligent early warning, clarifying core rules concerning data sharing, algorithm filing, early warning issuance, division of rights and responsibilities, and privacy protection.[10] Technical standards, evaluation norms, operational procedures, and ethical guidelines should be established and improved simultaneously, unifying requirements such as early warning classification, model testing, effect evaluation, and information release, thereby promoting the transformation of intelligent early warning from fragmented exploration to standardized and normalized operation. At the same time, the rights and responsibilities of multiple stakeholders should be scientifically delineated, and mechanisms for responsibility determination for early warning deviations and for fault tolerance and correction should be improved. Such measures will not only consolidate the early warning responsibilities of each stakeholder but also reserve reasonable space for technological innovation and pilot exploration, achieving a dynamic balance between standardized development and breakthrough innovation.

4.2 Deepening Data Integration and Creating an Integrated High-Quality Governance Pattern

Data governance serves as the foundational project for improving the effectiveness of intelligent

early warning. We must address the problems of barriers and quality through institutionalized, systematic, and normalized approaches. We should accelerate the construction of cross-departmental, cross-regional, and cross-level emergency data hubs and sharing and exchange platforms, and clarify data sharing catalogs, permission boundaries, flow processes, and security specifications. Such efforts will resolve the long-standing difficulties of being unwilling, afraid, or unable to share data from the institutional and mechanistic levels.[11] We need to establish a data quality management mechanism covering the entire life cycle of collection, aggregation, cleaning, labeling, updating, and verification, unify norms and technical standards, and strengthen dynamic feedback and continuous improvement, thereby comprehensively enhancing the completeness, accuracy, timeliness, and usability of the data. Under the premise of strictly protecting national security, public security, and personal privacy, we should promote the orderly integration of government data, enterprise data, and social data, and build an emergency data resource system featuring full-domain coverage, dynamic updating, security and controllability, and open sharing, so as to provide a high-quality data foundation for intelligent early warning.

4.3 Strengthening Algorithm Supervision and Enhancing the Credibility and Fairness of Early Warning

Algorithm governance directly concerns the credibility and reliability of intelligent early warning. We should adhere to the basic principles of controllability, interpretability, fairness, and safety, and build a full-chain regulatory system. We should promote the implementation of a filing management system and a third-party audit system for high-risk early warning algorithms, and establish a whole-process supervision mechanism covering design, testing, deployment, operation and maintenance, iteration, and decommissioning, so as to improve algorithm transparency and thereby reduce the trust risks and decision-making risks brought by the "algorithm black box." We should embed public values and fairness orientation into the model training and optimization process, strengthen the review of geographical bias, group bias, and scenario bias, reduce discriminatory early warnings and omitted early warnings, and safeguard the publicness and fairness of risk governance. We should improve the human-machine collaborative decision-making mechanism, clarify the positioning of algorithms as auxiliary decision-making tools, retain and strengthen experts' rights of review, intervention, and final decision, and enhance the stability, reliability, and adaptability of early warning in complex and extreme scenarios.

4.4 Improving the Coordination Mechanism and Shaping a Multi-Stakeholder Intelligent Early Warning Ecosystem

The level of collaborative governance determines the overall effectiveness of the intelligent early warning system. We must accelerate the construction of a multi-stakeholder governance pattern led by the government, empowered by enterprises, supported by research institutions, and participated in by society. We should optimize the internal coordination mechanism within the government, clarify the responsibilities of each department in risk perception, assessment, early warning, and response, unify the command platform and information release standards, and achieve a closed-loop efficient operation of perception-assessment-early warning-response-handling. We should improve the institutional arrangements for government-enterprise collaboration, clarify the channels, rights and responsibilities, incentives, and guarantee measures for enterprises to participate in emergency early warning, and steadily introduce technical, data, platform, and talent support. We should broaden the paths for social participation, strengthen the popularization of intelligent early warning science and public capacity training, enhance the public's ability to identify early warning information, response efficiency, and willingness to provide feedback, and form a modern intelligent early warning ecosystem featuring top-down linkage, internal and external coordination, multi-party participation, and joint construction and sharing.[12]

5. Conclusion

Against the backdrop of the deep coupling between the risk society and the digital society, artificial intelligence serves as the core support and an inevitable choice for breaking the inherent limitations of traditional early warning models, achieving preemptive prevention of major emergency risks, and advancing the modernization of emergency governance. This paper proposes systematic optimization paths from the four dimensions of institution, data, algorithm, and coordination, thereby providing a

clear action framework and key practical guidance for resolving the deep governance dilemmas currently faced by artificial intelligence in risk early warning for emergencies and for transforming technological advantages into governance effectiveness. In the future, we must always adhere to the core value orientation of public governance, continuously promote the deep adaptation and dynamic integration of technological logic and governance logic, innovate within regulation and regulate within innovation, constantly improve the governance system for intelligent early warning, continuously enhance China’s capacity to prevent and resolve major risks, and build a solid technological and institutional barrier for safeguarding national public security and social stability.

References

[1] Zhang Liang. Research on the Construction of an Urban Risk Event Early Warning Response Framework from the Perspective of Risk Governance. Journal of East China University of Science and Technology (Social Science Edition), 2020, 35(03): 112-125.

[2] Zhang Haibo, Dai Xinyu, Peng Yi, et al. New-Generation Information Technology Empowering the Modernization of National Emergency Management: Technology Foresight and Policy Suggestions Based on Typical Scenarios. Bulletin of Chinese Academy of Sciences, 2025, 40(10): 1674-1685.

[3] Xu Jianhua, Zheng Xuezhao, Ma Haitao, et al. Multi-Dimensional Integration and Innovative Development Paths for the Construction of Natural Disaster Emergency Rescue Systems. Bulletin of National Natural Science Foundation of China, 2025, 39(06): 939-949.

[4] Yang Jixing, Fang Yudong, Bian Lu, et al. Research and Application Exploration of the Digital Battlefield System for Emergency Rescue. China Safety Science Journal, 2023, 33(10): 240-246.

[5] Zhong Shuang, Xu Xiaofeng. Application of Artificial Intelligence in Emergency Management and Its Risk Classification: A Review Study Based on Literature and Cases. Journal of Beijing University of Aeronautics and Astronautics (Social Sciences Edition), 2024, 37(05): 26-40.

[6] Peng Bo, Lin Minghai. Artificial Intelligence Addressing National Security Risks: The Path of Technological Reshaping of Bureaucratic Governance. Journal of Shanghai Jiao Tong University (Philosophy and Social Sciences Edition), 2025, 33(10): 15-32.

[7] Hou Guanghui, Li Zhao. The Development Status, Difficulties and Hidden Concerns, and Practical Approaches of Artificial Intelligence Empowering the Modernization of Emergency Management. China Emergency Management Science, 2025, (06): 87-100.

[8] Liu Yinxi, Zhang Chunyan. Digital Empowerment of Emergency Management Collaboration: Structural Response, Mechanism Operation, and Effectiveness Output. Nanjing Social Sciences, 2024, (09): 60-69.

[9] Zhang Tao, Ma Haiqun. Research on the Construction of a Data and Algorithm Risk Identification Model in Intelligent Intelligence Analysis. Journal of the China Society for Scientific and Technical Information, 2022, 41(08): 832-844.

[10] Yu Haiyan, Zhu Weiqi. Artificial Intelligence Risk Identification and Governance Path Construction. Information Studies: Theory & Application, 2026, 49(01): 30-40.

[11] He Jun, Fang Ximeng. Research on Artificial Intelligence Regulation Based on the Synergy of Data Governance and Algorithm Regulation. Journal of Dongbei University of Finance and Economics, 2025, (05): 25-35.

[12] Xie Xiao, Luo Shijie. On the Dynamic Risks and Adaptive Governance of Generative Artificial Intelligence. Journal of Beijing University of Technology (Social Sciences Edition), 2025, 25(01): 112-125.

[13] Li Shiyue. The Internal Mechanism and Optimization Path of Digital Technology Empowering the Operating Rules of Emergency Management. Administrative Tribune, 2023, 30(05): 122-129.

[14] Zhou Limin, Long Zhiguang. Disaster Early Warning Innovation in the Era of Big Data: A Case Study of the Yangjiang Emergency Early Warning Information Release Center. Wuhan University Journal (Philosophy and Social Sciences Edition), 2017, 70(03): 121-132.

[15] Xiong Li, Wang Kun, Chen Nan, et al. Research on an Emergency Risk Information Early Warning System Driven by Data Stream Learning. Information Studies: Theory & Application, 2023, 46(07): 140-149.