Proceedings of the 3rd International Conference on Global Politics and Socio-Humanities
DOI: 10.54254/2753-7048/2025.24563

# *Research on the Mechanism of Safety Risk Prevention in Urban Underground Space—Analytical Perspective Based on Digital Resilience*

**Shunyue Wen[1], Na Wang[1*], Qianyu Bao[1]**

[1]*Law School, Zhejiang Normal University, Jinhua, China*
**Corresponding Author. Email: 3496562179@qq.com*

***Abstract.*** The safety of urban underground space is a key part of urban public safety. To address the challenges of underground safety, such as hidden dangers and difficulties in disposal, constructing digital underground spaces to enhance the safety of urban operations has become an effective strategy. This study focuses on the application of digital technology in the prevention of safety risks in underground spaces. By integrating governance and system resilience theories, a digital resilience analysis framework was constructed, and a practical case study of H city was used to analyze how digital technology integrates governance entities, forming a triple driving force to prevent risks and enhance urban resilience. Research shows that digital technology has achieved real-time monitoring, risk assessment, and precise disposal of underground hazards by promoting data fusion, model construction, and cross departmental cooperation, significantly improving the efficiency of urban underground space safety governance.

***Keywords:*** underground space, risk prevention, digital resilience, urban public safety

## 1. Introduction

Urban public safety is a core support for the modernization of national governance and a key pillar in building a safe China and advancing Chinese-style modernization. Currently, the urban public safety governance model is shifting from 'post-incident response' to 'pre-incident prevention,' using digital empowerment, systematic governance, and multi-party collaboration to build a solid foundation for people's safety, social stability, and high-quality development [1]. As a strategic pivot for urban public safety, the risk management of urban underground space is a critical component of this transformation. Compared to traditional ground-level safety hazards, urban underground risks are characterized by their concealment, suddenness, and spreadability [2]. Traditional emergency management models struggle with difficulties in prediction, delayed responses, and limited damage control when dealing with underground risks, making it urgent to leverage digital technology to address these challenges.

This study employs the theories of integrated governance and system resilience to construct an analytical framework from a digital resilience perspective. It elucidates how digital technology reshapes governance logic, shifting risk prevention from post-incident response to proactive

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prevention. By integrating governance entities, optimizing governance tools, and improving governance mechanisms, digital technology provides theoretical support for enhancing the urban emergency management system, thereby facilitating the modern transformation of urban safety governance.

## 2. Case selection and background introduction

This study examines the transformation of underground hazard prevention in H City through field research and questionnaires, analyzing digital technology's role by comprehensively assessing the creation, operation, and feedback of its intelligent prevention system to ensure scientific conclusions. As a megacity with complex geological conditions and frequent underground risks hindering sustainable development, H City faces significantly intensified infrastructure scale and space utilization complexity due to rapid urbanization. Given its sensitive geology causing rapidly increasing hazards and inadequate traditional governance, innovative mechanisms are urgently needed. Driven by national policy, H City leverages digital technology to develop an intelligent prevention system integrating information, establishing monitoring networks, applying risk models, and achieving closed-loop management—marking initial governance transformation.

Selected for its typicality, innovation, and data availability, H City's governance experience offers valuable insights for other cities, while its digitally-driven model shift, new mechanisms, and the research team's first-hand field data provide a solid analytical foundation.

## 3. Case analysis

### 3.1. The concept of urban underground space risk prevention

Preventive governance is a key concept in the development of resilient cities, aiming to identify risk factors early through technological means, thus transitioning from crisis response to risk prevention [3]. From the perspective of public administration, the construction of H City's intelligent underground hazard prevention system exemplifies the innovation in preventive and collaborative governance concepts. Traditional urban governance often operates in a reactive mode, whereas H City leverages digital twin technology to shift the focus of governance forward, achieving a transition from crisis response to risk prevention, as shown in "Figure 1 ". By creating a virtual mirror image of underground spaces, the system can predictively simulate potential hazards, identifying risk factors in advance, which aligns with the preventive governance philosophy of 'treating before the disease occurs.'

#### 3.1.1. Conceptual core

Through scientific risk prevention, collaborative governance, and technological foresight, the underground space management of City H has developed a governance framework that is data-driven, collaboratively managed, and technologically empowered. By leveraging multi-source information and innovative algorithm models, a risk prediction system has been established, featuring 'comprehensive element perception, grid-based assessment, and dynamic early warning,' marking a shift from traditional manual inspections to scientific predictions.

The city has established a cross-departmental coordination mechanism to integrate underground space data into the City Information Model (CIM) platform, forming a data sharing pool and a community of shared responsibility, which has improved decision-making and execution efficiency. The system uses IoT sensors and digital twin models to monitor risks in real time and generate

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predictive reports on risk evolution, providing visual and verifiable decision-making support for preventive measures.

### 3.1.2. Concept implementation

In the process of constructing the preventive governance system of H City underground space, policy logic and demand drive form a dual power mechanism of top-level design traction and realistic pressure transmission, which jointly promote the governance paradigm from traditional bureaucracy to technology-enabled governance [4].

The national strategic plans and departmental policy documents form the 'legitimacy framework' and 'resource allocation map' for governance innovation. The 14th Five-Year Plan designates 'digital twin cities' as a key direction in new urbanization, providing strategic positioning and policy endorsement for H City's technological innovation in underground hazard prevention. The 'Guiding Opinions on Accelerating the Construction of New Urban Infrastructure,' jointly issued by the Ministry of Housing and Urban-Rural Development and six other departments, further includes intelligent monitoring systems for underground spaces in the scope of new urban infrastructure. This policy transmission mechanism, through the authoritative empowerment path of 'high-level promotion,' breaks down the resource allocation barriers under the traditional system —— Just as the deliberation and coordination body in Northwest H County achieves authoritative transmission through county leaders taking the lead [5], it elevates the application of digital twin technology to a strategic project in urban governance.

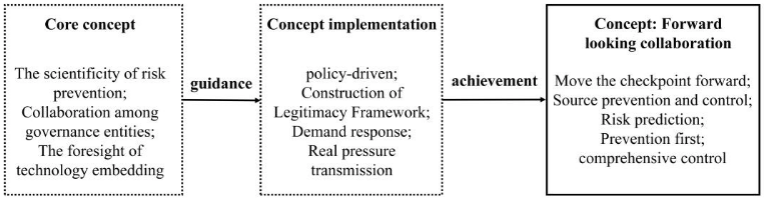


Figure 1: "Forward-looking Synergy" analysis framework from the perspective of digital resilience

## 3.2. The structure of the transformation of preventive governance: flexible integration

The intelligent prevention application system for underground hazards in City H demonstrates dual elastic characteristics of 'technology-organization.' By leveraging digital technology, the system has restructured its governance framework, breaking through the rigid constraints of traditional hierarchical systems to create a flexible mechanism that meets complex governance needs. This structural flexibility is primarily reflected in two aspects: the flexibility of data integration and the dynamism of organizational collaboration, as shown in "Figure 2 ".

### 3.2.1. Data integration: from "information islands" to "digital base"

In the development of smart cities, data sharing is crucial for enhancing governance efficiency. By enforcing administrative orders and technical standards, it can effectively break down information silos and establish a unified digital foundation [6]. City H uses the city information model (CIM) as its data foundation, integrating multi-source heterogeneous data, including a 900-square-kilometer geological body model, 25,000 kilometers of pipeline data, and 1,749 foundation pit engineering records. City H adopts a dual governance strategy: first, using administrative orders to break down data barriers, incorporating data collection into performance evaluations through urban

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infrastructure policies, clarifying departmental responsibilities for data sharing, and assigning data tasks administratively to form a three-tier responsibility chain. Second, by standardizing data formats through technical standards, City H has developed the 'Technical Specifications for Underground Space Data Governance,' created data cleaning and conversion tools, and established a comprehensive technical control system.

### 3.2.2. Organizational coordination: from "sectoral division" to "network governance"

H City's underground space governance system integrates vertical hierarchical pressure transmission, horizontal departmental coordination and linkage, and multi-subject participation, forming a modern urban underground public safety governance structure. This system establishes a three-tier governance momentum chain: the Municipal Construction Commission sets standards and coordinates resources; county governments form working groups; and communities achieve task closure digitally. Centered on the 'Joint Meeting on Hazard Prevention', it integrates 17 functional departments to overcome fragmented governance, while multi-stakeholder participation creates a complementary network—exemplified by collaboration with the Chinese Academy of Sciences to enhance risk identification and with security groups to build data security protection. Through its intelligent prevention application system enabling data integration and organizational collaboration, H City constructs a modern governance system that enhances urban public safety efficiency, provides a composite governance model for megacity modernization, and enriches Chinese public management theory and practice.

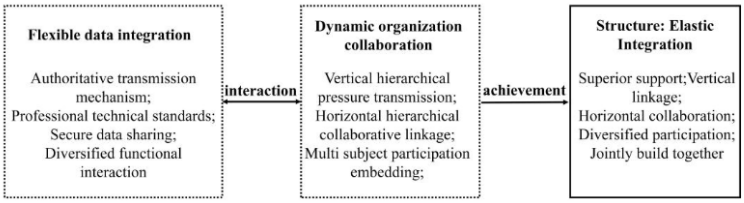


Figure 2: "Resilient integration"analysis framework from the perspective of digital resilience

## 3.3. Mechanism of transformation of preventive governance: dynamic feedback

From the perspective of digital resilience, a dynamic feedback mechanism can enhance the emergency coordination capabilities of urban systems through real-time monitoring and intelligent early warning, thereby continuously improving governance efficiency [7]. As shown in "Figure 3 ", The intelligent prevention system for underground hazards in City H employs a closed-loop mechanism of 'monitoring-early warning-handling-evaluation' to achieve dynamic management of underground hazards. This mechanism draws on the 'adaptive cycle' principle from system resilience theory and integrates the characteristics of digital technology, reflecting an organic connection between four key aspects: real-time monitoring, intelligent early warning, precise handling, and continuous improvement.

### 3.3.1. Real-time monitoring

Real-time monitoring is crucial for the governance of underground spaces in City H. By leveraging sensor networks and IoT technology, a real-time mapping between physical and digital spaces has been established, shifting from manual inspections to technological perception. The systematic application of these tools has overcome the information limitations of traditional governance

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methods. In risk areas, City H has deployed intelligent devices to create a 'perception neural network,' enabling millimeter-level monitoring. NB-IoT technology has established a real-time data link, achieving minute-level response times. This monitoring system enhances administrative mechanisms through technological means, forming a defense line characterized by technological perception, data-driven decision-making, and precise early warnings. It provides data support for governance and changes the perception of risks.

### 3.3.2. Intelligent early warning

Intelligent early warning is the core of risk governance. By using algorithm models and a tiered response mechanism, a risk filtering system that integrates digital technology with administrative intervention has been established, enhancing governance capabilities. In City H, the 'Collapse Risk Factor Analysis Model' combines machine learning and expert knowledge to assess risks in real-time and generate early warning reports. The response mechanism includes a three-tier early warning rule, forming a hierarchical governance structure that leverages the advantages of a hierarchical system. Intelligent early warning achieves a closed-loop coordination between technical and administrative decision-making through a dual-track mechanism of technology and administration.

### 3.3.3. Precise disposal

Precision in handling is crucial for risk management. By updating the emergency plan database, optimizing the layout of emergency forces, and standardizing the process system, a 'standardized process-resource-intensive' handling system is established to enhance governance efficiency. City H has developed a 'hidden danger handling plan database' using historical cases, enabling automatic matching of warning information with handling plans, generating 'handling instructions,' and pushing them through the government platform. The dynamically updated plan database continuously optimizes the handling process. GIS technology visualizes emergency forces spatially and optimizes routes, shifting the layout of emergency resources from 'administrative-led' to 'demand-driven,' improving resource allocation efficiency and enhancing the resilience of urban public safety governance.

### 3.3.4. Continuous improvement

Continuous improvement serves as the updating mechanism of the governance system, fostering an integrated governance ecosystem through data feedback and public participation, thereby promoting the upgrade of governance models. Internally, the system achieves self-evolution through a closed-loop process of 'data-driven learning.' Externally, it enhances collaboration through a 'risk reporting' mini-program, enabling citizens to participate in risk monitoring and forming a collaborative network between the government and the public. This mechanism leverages technology to empower social forces in governance, broadens the scope of monitoring, enhances public engagement, and boosts the resilience of the governance system.

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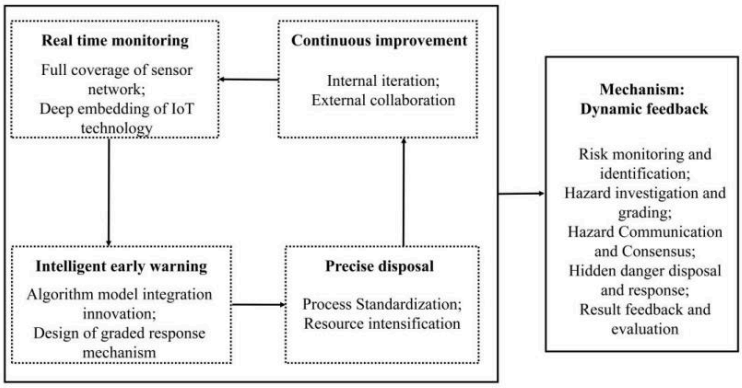


Figure 3: “Dynamic feedback” analysis framework from the perspective of digital resilience

## 3.4. Case summary

Digital twin technology drives the modernization of urban underground space governance. By integrating sensor networks and constructing isomorphic systems, it enables a shift from passive to proactive governance. Through its "data-algorithm-action" closed-loop mechanism, it breaks through traditional limitations and facilitates intelligent upgrades of public management tools and processes. Furthermore, it establishes cross-departmental data-sharing platforms to dismantle information barriers, enabling multi-agency collaboration. Extending to emergent risk domains, it propels urban governance toward risk-based management beyond crisis response, fulfilling the modernization requirements of national governance systems.

The sustainability of technological innovation relies on the robust support provided by institutional frameworks. City H has incorporated the technical system for urban underground space safety governance into the ‘Regulations on Urban Underground Space Safety Management,’ marking a significant shift from ‘technology-driven project-based innovation’ to ‘institution-driven routine governance.’

## 4. Conclusion

The intelligent prevention system for underground hazards in City H demonstrates the deep integration of digital technology and public management, effectively addressing the challenges of managing underground spaces in megacities and serving as a model for the transformation of urban safety governance. This case highlights the logic of ‘technology-institution-context co-evolution,’ where digital twin technology requires institutional innovation to support it. The application of technology faces challenges such as data privacy, which opens up opportunities for future research. In the future, urban governance will evolve towards ‘precision, intelligence, and collaboration.’ The experience of City H shows that integrating technological innovation into the deep logic of governance system reform can achieve the transition from ‘modernizing governance tools’ to ‘modernizing governance capabilities,’ providing solutions for the modernization of governance in megacities.

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