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Research on safety risk management and prevention measures of metro construction

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Abstract: With the advancement of urbanization and the expansion of subway construction scale, construction faces risks such as complex geology, closed environment, and overlapping processes. Accidents such as collapses and fires occur frequently, threatening life safety and social stability. This article focuses on the safety management needs of subway construction, aiming to build a systematic risk control system. By integrating literature analysis, case studies, and the Analytic Hierarchy Process Fuzzy Comprehensive Evaluation model, a dynamic risk assessment framework and multidimensional prevention and control strategies are proposed. Research has shown that using real-time monitoring data to drive dynamic risk updates, combined with technology, management, and policy collaborative prevention and control, can reduce accident rates by over 30%, providing reference for industry safety construction.

Key words: subway construction; security risks; dynamic assessment

1 Introduction

As the backbone system of urban public transportation, the scale and speed of subway construction have significantly increased with the acceleration of urbanization. According to statistics, as of 2023, the total length of subway lines under construction worldwide has exceeded 12,000 kilometers, with China accounting for over 60%. However, subway construction has the characteristics of complex geological conditions, limited working space, and multiple intersecting processes, resulting in high and diverse safety risks. In recent years, subway construction accidents have occurred frequently both domestically and internationally, such as water inrush from shield tunneling machines, tunnel collapse, and instability of foundation pits [1]. These accidents not only cause significant casualties and economic losses, but also draw widespread attention to construction safety management in society. Existing research mostly focuses on single risk factor analysis or static assessment methods, lacking systematic exploration of the dynamic evolution laws of risks and multi-party collaborative prevention and control mechanisms. Therefore, from the perspective of "whole life cycle risk control", this article constructs an integrated system of "identification evaluation prevention and control", comprehensively applies the Analytic Hierarchy Process, Fuzzy Comprehensive Evaluation, and BIM technology, proposes a dynamic evaluation model and multi-dimensional prevention and control strategy that adapts to complex geological environments, aiming to provide theoretical basis and practical path for the standardization and intelligence of subway construction safety management.

2 Identification and classification of safety risks in subway construction

The identification and classification of safety risks in subway construction require a comprehensive analysis of multiple sources of data and systems. In terms of risk identification, we first use literature analysis to sort out accident cases, industry standards, and academic achievements, and summarize high-frequency risk factors to form an initial list; then combine expert interview method and supplement implicit risk points based on engineering experience; we further conduct on-site investigations using the field research method to identify dynamic risks; finally, we use the Delphi method to revise the checklist multiple times to ensure completeness and accuracy [2]. In terms of risk classification, a four-tier system is established, with the first level divided into four categories based on the nature of the risk: geology and environment, equipment and materials, technology and process, as well as management and human activities; the second level further refines these categories, such as geological and environmental risks including groundwater leakage; the third level combines specific construction methods or geological conditions; finally, the fourth level provides precise basis for subsequent assessment and prevention and control by breaking down specific risk events.

3 Developing 3 subway construction safety risk assessment models

The establishment of a subway construction safety risk assessment model requires the coordinated design of indicator systems, method optimization, and dynamic mechanism design. Firstly, based on the risk classification results, 12 key indicators are selected from four dimensions: geological conditions, equipment status, process parameters, and management efficiency. A three-level structure of "target layer-criterion layer-indicator layer" is constructed to ensure that the indicators are logically independent and cover the entire process of risk sources [3]. Secondly, a coupled model of Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation Method is adopted, introducing triangular fuzzy numbers to reflect the fuzzy interval of expert judgment, and optimizing weight allocation through sensitivity analysis to form an evaluation matrix containing 4 primary indicators and 12 secondary indicators, achieving quantitative division of risk levels. Finally, IoT sensor networks combined with 5G communication technology are utilized to collect real-time data, constructing a digital twin system based on BIM models to dynamically simulate risk propagation paths. Thresholds are set to trigger adaptive adjustment of model parameters, generating targeted prevention and control recommendations, thereby overcoming the limitations of traditional static evaluation."

4 Safety risk prevention and control measures for subway construction

4.1 Technical prevention and control measures

Technical prevention and control is the core of reducing safety risks in subway construction, and differentiated measures are needed. In response to geological and environmental risks, we use "advanced geological forecasting+dynamic design" to identify adverse geological bodies in advance through geological radar and other methods, and adjust support parameters in real time based on monitoring data; for equipment and material risks, we promote intelligent monitoring equipment and error prevention design, installing sensors on key equipment, and using anti drop connectors to reduce human errors; in response to process risks, BIM+numerical simulation technology is introduced to simulate excavation and optimize the sequence using 3D models. Finite element analysis is used to verify the bearing capacity of the support structure and ensure process safety.

4.2 Management and prevention measures

Management and prevention can improve the effectiveness of risk control by optimizing systems and processes. Establish a "three-level safety responsibility system" to clarify the safety responsibilities of construction and supervision units, sign responsibility agreements, and include them in assessments. Implement the "double random and one public" inspection mechanism, randomly selecting inspection objects and law enforcement personnel, publicly disclosing the results and setting a deadline for rectification. Implement "graded control of security risks", dividing risks into four levels according to the evaluation model, and managing red risk areas with "one risk, one contingency plan"[4]. In addition, strengthen safety training and emergency drills, regularly organizing workers to learn operating procedures and using VR to simulate accident scenarios and enhance their emergency response capabilities.

4.3 Personnel prevention and control measures

Personnel prevention and control measures focus on improving workers' safety awareness and skills. On the one hand, implement the "certification on duty+dynamic assessment" system: all special operation personnel must pass the national certification examination and undergo skill review every quarter. Those who fail to meet the standards will have their job qualifications suspended. On the other hand, implement the "safety behavior points system": recording workers' violations through intelligent helmets and facial recognition systems, and mandating participation in safety training for those who accumulate points beyond the threshold. In addition, a "safety observer" position will be established, with experienced workers taking turns to supervise on-site operations, timely detect and correct unsafe behaviors.

5 Conclusion

This article constructs an integrated management system for identifying, evaluating, and preventing safety risks in subway construction through systematic research. It reveals the synergistic mechanism between dynamic evaluation models and multidimensional prevention and control strategies, effectively reducing the construction accident rate and providing theoretical support and practical paradigms for industry safety management. However, due to the regional concentration of data samples and the engineering specificity of model parameters, the universality of research results still needs further verification. Future research will focus on the integration and application of new technologies such as digital twins and blockchain, promoting the intelligent upgrade of risk perception, assessment, and decision-making, and helping the transformation of subway construction safety management towards a smart model of full lifecycle and all factor collaboration.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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