Big Data-Based Highway Tunnel Maintenance Decision-Making Postprint

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Abstract

To address the challenges in highway tunnel maintenance decision-making posed by numerous facilities and heterogeneous, dispersed information characteristics, this paper conducts research on tunnel maintenance assessment and optimization using big data analysis, based on an analysis of highway tunnel maintenance features and proceeding from tunnel life-cycle information. Centering on life-cycle maintenance assessment methods and optimization decision-making, the article describes the fundamental principles and implementation pathways of life-cycle information assessment and decision-making, and selects maintenance strategies under constrained conditions based on assessment results. Finally, the article summarizes the innovative points and application effects of this method, and identifies future development trends for tunnel maintenance assessment.

Full Text

Preamble

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Highway Tunnel Maintenance Decision-Making Based on Big Data

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Abstract: To address the challenges posed by the numerous facilities and heterogeneous, dispersed information in highway tunnel maintenance decision-making, this paper analyzes the characteristics of highway tunnel maintenance and investigates tunnel maintenance assessment and optimization using big data analytics based on whole lifecycle information. Focusing on whole lifecycle maintenance assessment methods and optimization decision-making, the article describes the fundamental principles and implementation pathways of whole lifecycle information assessment and decision-making, and selects maintenance strategies under constrained conditions according to evaluation results. Finally, the paper summarizes the innovative aspects and application effects of this method and identifies future development trends in tunnel maintenance assessment.

Keywords: Highway Transportation; Operation and Maintenance; Decision Support System; Road Tunnel; Life Cycle; Building Information Modeling

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2 System Function and Requirement Analysis

In recent years, tunnel construction in China has developed rapidly, with records for tunnel length and quantity being continuously broken. As critical urban infrastructure, highway tunnels and metro tunnels bear important urban transportation functions. According to statistics from the Ministry of Transport, by the end of 2013, there were 11,359 highway tunnels nationwide with a total length of 9,605.6 km [1]. However, tunnel operation and maintenance technologies have not kept pace with this rapid construction growth. As urban development progresses, China' s tunnels have transitioned from large-scale construction to operation and maintenance phases, placing higher demands on tunnel operation and maintenance management technologies. Currently, highway tunnel maintenance management remains difficult to grasp comprehensively, with maintenance funding decisions and tunnel health condition assessments proving challenging to evaluate accurately. To implement regular, timely, and preventive maintenance for highway tunnels and achieve standardized, normalized, and intelligent tunnel maintenance management, this paper proposes a method for tunnel maintenance scheme assessment and decision-making systems based on BIM, IoT, big data, and cloud computing technologies from a whole lifecycle information perspective.

Highway tunnel maintenance management primarily involves the collection, storage, retrieval, and analytical processing of various maintenance data to improve data utilization efficiency and extract useful information, thereby enhancing management efficiency and reducing costs [2]. Through research on tunnel disease formation mechanisms, tunnel disease evaluation and treatment strategies, and analysis of management models, business requirements, user needs, and business processes of highway tunnel management departments, the following overall requirements are proposed:

(1) **Standardized and normalized management and storage of highway tunnel construction and maintenance data:** Establish detailed technical condition, geographic, and attribute databases for civil tunnel facilities throughout their lifecycle to effectively manage various highway tunnel maintenance data, and provide efficient data collection methods and flexible data update and maintenance approaches.

(2) **Highway tunnel disease evaluation and decision-making:** Tunnel disease evaluation should address structural diseases in tunnels, predict disease development trends, and assess both the disease severity level and the overall service level of the entire tunnel through structural disease analysis models combined with specifications and standards.

(3) **Highway tunnel disease treatment strategies:** Store expert maintenance strategies for various types and levels of structural diseases.

(4) **Highway tunnel maintenance plan formulation:** Based on the safety evaluation grades determined by disease assessment and predictions of disease development trends, formulate maintenance plans and calculate maintenance costs under different constraints through data analysis to generate maintenance plan reports.

2.1 System Process Design

The tunnel maintenance decision-making evaluation process is shown in Figure 1 [Figure 1: see original paper].

2.1.1 Intermediate Database The intermediate database stores data required for system assessment and decision-making. It extracts data from other operation and maintenance systems used in the Dalian Road Tunnel through intermediate tables, such as basic tunnel structure information, routine inspection results, periodic inspection results, and special inspection results from the tunnel maintenance management system. The structural health monitoring system collects real-time tunnel structural health data through sensors, including longitudinal settlement, joint opening, and cross-section convergence.

2.1.2 Structural Assessment For existing tunnel diseases, the system evaluates the structural disease grade through tunnel evaluation decision-making mathematical model algorithms combined with specifications and standards. When establishing the shield tunnel structural safety assessment index system, given the difficulty of considering all details at once, the hierarchical principle from systems science is adopted—specifically, the decomposition-coordination principle from large system theory. This approach decomposes the problem into multiple levels, each containing multiple components, allowing progressive analysis from coarse to fine, from surface to depth, and from global to local perspectives. This method organizes and hierarchizes the numerous factors affecting shield tunnel structural safety conditions, thereby establishing a hierarchical analytic model. In other words, the Analytic Hierarchy Process (AHP) concept is used to establish the shield tunnel structural safety assessment index system [3], as shown in Figure 2 [Figure 2: see original paper] and Figure 3 [Figure 3: see original paper].

Due to R language' s unique advantages in big data processing and analysis, the mathematical model is built by writing the assessment system into R scripts placed on the system' s backend server. The backend server contains many independent algorithm subprograms controlled by a unified model center. Figure 4 [Figure 4: see original paper] presents the data model control framework, which includes two sub-modules: model configuration and model execution. Model configuration is used for algorithm parameter settings, model training and storage, and monitoring of model operation status, while model execution is used for model invocation and output of judgment results.

The basic architecture of the data analysis backend server primarily consists of two parts (as shown in Figure 5 [Figure 5: see original paper]):

1) **Application Program:** A console program built using Microsoft' s .NET Framework technology provides support for database reading and storage, file access, data preprocessing, and periodic scheduling.
2) **R Server:** An R language analysis engine built using Revolution' s DeployR Framework technology provides API interfaces for application program access and model loading functions, scheduling and controlling multiple R Session scripts to execute complex algorithm calculations.

2.1.3 Maintenance Strategy Selection Based on the assessment results, different maintenance strategies can be selected according to different scheme requirements. Taking the Dalian Road Tunnel as an example, the system provides two different maintenance strategies: performance-first and economy-first. Under the economy-first strategy, facilities in the unacceptable risk zone are prioritized for maintenance based on assessment results, while facilities in the negligible risk zone are temporarily excluded from maintenance considerations [4]. The performance after implementing this maintenance strategy is then estimated and compared with the annual budget. If requirements are met, the maintenance plan is output.

The performance-first method addresses maintenance priority issues under budget constraints by employing the "minimum weighted sum of squared deviations" concept from multi-attribute decision-making group ranking methods [5]. Priority ranking is a widely adopted method both domestically and internationally. Under limited funding conditions, this approach prioritizes projects with significant impact, poor technical condition, and high maintenance grades to achieve rational allocation and use of limited funds, ensuring projects maintain specified service levels and that maintenance funds deliver optimal economic and social benefits.

3 Engineering Application

Highway tunnel whole lifecycle maintenance decision-making is of great significance for improving highway tunnel maintenance management levels and efficiency, ensuring tunnel structural safety, and reducing operation and maintenance costs. Currently, this system has been applied in the maintenance management of Shanghai' s Dalian Road Tunnel, enabling standardized data collection, intelligent analysis and processing, scientific maintenance decision-making, and information-based business management. This provides technical means for management departments to promptly identify diseases and implement scientific prevention and control measures, thereby reducing accidents and ensuring safe and smooth tunnel operation.

Figure 6 [Figure 6: see original paper], Figure 7 [Figure 7: see original paper], and Figure 8 [Figure 8: see original paper] show real-time monitoring data of tunnel cross-section convergence, joint opening, and longitudinal settlement. Figure 9 [Figure 9: see original paper] displays structural assessment segments at dangerous levels based on disease evaluation results and provides maintenance recommendations. Figure 10 [Figure 10: see original paper] presents the annual maintenance plan calculated under constrained conditions based on structural health assessment results combined with maintenance specifications.

Given the current situation where numerous management systems exist for tunnel operation and maintenance, this paper proposes a new approach for urban highway tunnel operation and maintenance by adopting an intermediate database to extract and integrate information required for tunnel assessment, combined with the big data analysis advantages of R language, to realize tunnel service condition assessment and generate annual maintenance plans under constrained conditions. However, the current system' s assessment index parameter acquisition method uses the latest time data. How to consider the impact of sudden changes in assessment index data on structural assessment segments warrants further research.

References

[1] WANG Bo. Computer Management System for Civil Structure Maintenance of Xiamen Xiang' an Subsea Tunnel [D]. Southwest Jiaotong University, 2009.

[2] ZHOU Jian, YANG Yang, FU Lijia. Research on Highway Tunnel Preventive Maintenance Management System [J]. Highway Traffic Technology, 2011, 06: 131-134.

[3] XU Hui, ZHANG Lijing, YU Jianping, ZHANG Erqiang. Application of Extended Scale AHP in Safety Assessment of Shanghai Yangtze River Tunnel Facilities [J]. Industrial Safety and Environmental Protection, 2013, 10: 49-52.

[4] LIU Yanfang, ZHOU Yongtao, BAO Weigang. Research on Priority Ranking Method for Bridge Structure Maintenance Schemes [J]. Highway, 2013, 04: 201-204.

[5] XIA Haibing, YAO Anlin, YIN Jiming. Auxiliary Decision-Making Method for Bridge Maintenance Priority in Road Network [J]. Highway Traffic Technology, 2007, 02: 121-122+132.