

## Big Data-Based Highway Tunnel Maintenance Decision-Making Postprint

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### Abstract

To address the difficulties in highway tunnel maintenance decision-making arising from the numerous facilities and heterogeneous, dispersed information characteristics of highway tunnels, this paper, based on an analysis of highway tunnel maintenance features, conducts research on tunnel maintenance assessment and optimization utilizing big data analysis from the perspective of tunnel life-cycle information. The article focuses on life-cycle maintenance assessment methods and optimization decisions, describing the fundamental principles and implementation pathways of life-cycle information assessment and decision-making, and performs maintenance strategy selection under constrained conditions based on the assessment results. Finally, the article summarizes the innovative aspects and application effects of this method, and identifies the future development trends of tunnel maintenance assessment.

### Full Text

### Preamble

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### Research on Highway Tunnel Maintenance Decision-Making Based on Big Data

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**Abstract:** To address the difficulties in highway tunnel maintenance decision-making caused by numerous facilities and heterogeneous, dispersed information, this paper analyzes the characteristics of highway tunnel maintenance and investigates tunnel maintenance assessment and optimization using big data analytics from a whole lifecycle information perspective. Focusing on whole lifecycle maintenance assessment methods and optimization decision-making, the paper describes the fundamental principles and implementation pathways of whole lifecycle information assessment and decision-making, and performs constrained maintenance strategy selection based on assessment 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; highway tunnel; lifecycle; 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 transportation functions. According to transportation department statistics, by the end of 2013, China had 11,359 highway tunnels 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 assessments proving challenging to evaluate accurately. To facilitate regular, timely, and preventive maintenance of highway tunnels and achieve standardized, normalized, and intelligent tunnel maintenance management, this paper proposes a method for a tunnel maintenance scheme assessment and decision-making system based on BIM, Internet of Things, 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, disease evaluation and treatment strategies, as well as analysis of management models, business requirements, user needs, and operational 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. This involves establishing detailed technical condition, geographic, and attribute databases for the entire lifecycle of tunnel civil facilities to effectively manage various highway tunnel maintenance data, while providing efficient data collection means and flexible data update and maintenance methods.
- (2) Highway tunnel disease evaluation and decision-making. This should address structural diseases in tunnels, predict disease development trends through structural disease analysis models combined with specifications and standards, and evaluate both disease severity grades and the overall service level of the entire tunnel.
- (3) Highway tunnel disease treatment strategies. This requires storing expert maintenance strategies for various types and grades of structural diseases.
- (4) Highway tunnel maintenance plan formulation. Based on disease safety evaluation grades and disease development trend predictions determined through evaluation, maintenance plans should be formulated and maintenance costs calculated under different constraints through data analysis to form 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, daily inspection results, regular 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** Structural assessment evaluates the severity of diseases within tunnels through tunnel evaluation decision-making mathematical models combined with specifications and standards. When establishing the shield tunnel structural safety assessment index system, it is difficult to consider all details of the problem at once. Therefore, the hierarchical principle from systems science is adopted, specifically the decomposition-coordination

principle from large system theory, which decomposes the problem into multiple levels with multiple factors at each level. This organizes and hierarchizes the numerous factors affecting shield tunnel structural safety status, establishing a hierarchical analytic model. In other words, the Analytic Hierarchy Process (AHP) methodology 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 numerous independent algorithm subroutines 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 setting, model training and storage, and model operation status monitoring, while model execution is used for model invocation and output judgment results.

The basic architecture of the data analysis backend server primarily consists of two parts (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** Different maintenance strategies are selected according to different scheme requirements. Taking the Dalian Road Tunnel as an example, the system provides two different maintenance strategies: performance priority and economic priority. Under the economic priority strategy, facilities in the unacceptable risk zone are prioritized for maintenance and repair based on assessment results, while facilities in the negligible risk zone are temporarily excluded from maintenance consideration [4]. Subsequently, performance estimation and annual budget comparison are conducted for the post-maintenance strategy performance. If requirements are met, the maintenance scheme is output.

The performance priority method addresses maintenance prioritization problems 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, projects with significant impact, poor technical condition, and high maintenance priority are arranged first to achieve rational allocation and utilization 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 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.

Figures 6 [Figure 6: see original paper], 7 [Figure 7: see original paper], and 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 constraints 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 and method 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 achieve 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 available data, and 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 Scale-Extended 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 Bridge Structure Maintenance Scheme Priority Ranking Method [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.

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*Note: Figure translations are in progress. See original paper for figures.*

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