Exploration of the Engineering Management Value of Tunnel Construction Monitoring Data

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Abstract. The complexity and scale of tunnel projects are increasing, and the value of construction monitoring data needs to be explored in depth. This paper constructs the engineering management value system of tunnel construction monitoring data, and analyses the value connotation and realization path of monitoring data in the four major fields of engineering decision-making, safety guarantee, quality control and cost management. The study shows that the monitoring data has been transformed from mere technical parameters to the core resources of engineering management, deepening the optimisation of construction plan, risk warning, quality assessment and cost control ability. Promoting the deep integration of monitoring data and project management, and realising the transformation from 'data collection' to 'value creation' are the key paths to improve the management level of tunnel project.

Keywords: tunnel construction; monitoring data; project management; value system; decision support

1 Introduction

As an important part of transport infrastructure construction, tunnelling faces increasingly complex geological conditions and higher safety risks[1]. In recent years, the scale and number of tunnelling projects in China have been growing rapidly, with the proportion of super-long tunnels, tunnels with super-large cross-sections and tunnels in areas with complex geological conditions increasing[2]. All these trends have greatly increased the construction difficulty and raised the overall risk of tunnelling projects. Under such circumstances, tunnel construction monitoring has become an indispensable tool to ensure project safety. It has gradually evolved from a traditional safety warning mechanism to an important resource for integrated project management.

However, although monitoring systems have been widely deployed, the depth of data application is still limited. Currently, a large amount of valuable monitoring data is mainly used for basic recording and post-event analyses. This underutilisation means that its wider potential - particularly in supporting forward-looking and strategic decision-making - has not been fully realised. The limited integration of monitoring data into engineering workflows restricts its effectiveness in improving project outcomes.

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The purpose of this paper is to establish the value system of tunnel construction monitoring data engineering management. It seeks to systematically explore the value connotation and realisation path of monitoring data from the four key dimensions of engineering decision-making, safety assurance, quality control and cost management. As a result, this study provides theoretical insights and practical guidance for promoting the in-depth application of monitoring data. Ultimately, this study aims to support smarter, safer and more efficient tunnelling practices by promoting data-driven management methods and improving the overall level of project governance.

2 Basic Concept of Tunnel Construction Monitoring

Tunnel construction monitoring is the systematic process of observing, measuring and analysing various physical and environmental parameters throughout the construction period of a tunnel project. This includes monitoring of peripheral rock deformation, surface settlement, internal forces in the support structure, groundwater pressure and other relevant factors[3]. Its main purpose is to understand the real-time condition of the tunnel and surrounding geology, to verify the accuracy of design assumptions and construction plans, to predict possible problems or failures, and to provide the necessary data to support informed construction decisions. A standard tunnel monitoring system consists of four core components: sensors, data acquisition equipment, a data transmission system and an analysis platform,as shown as Figure 1. Together they form a closed-loop management system that ensures continuous feedback from data collection to analysis and decision-making.

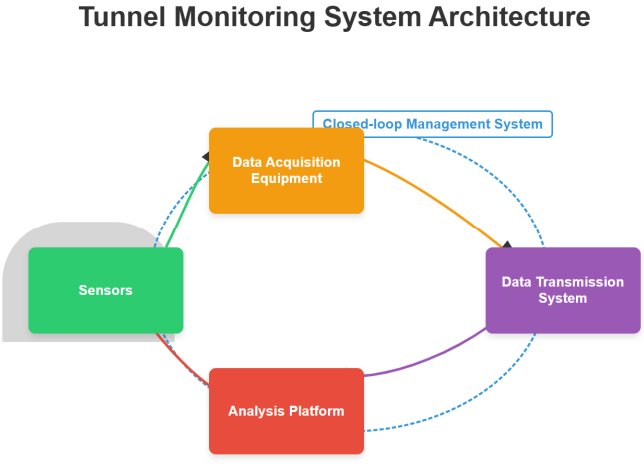

Fig. 1. Tunnel Monitoring System Architecture

With advances in information and sensor technology, tunnel construction monitoring has evolved from traditional manual measurements to highly automated, intelligent and web-based systems. These modern systems enable real-time data transmission and

analysis, improving the efficiency, accuracy and reliability of monitoring. As such, they play a vital role in enhancing construction safety, optimising engineering design, reducing risk and ensuring the long-term stability and quality of tunnel projects.

3 Current Status of Tunnel Construction Monitoring

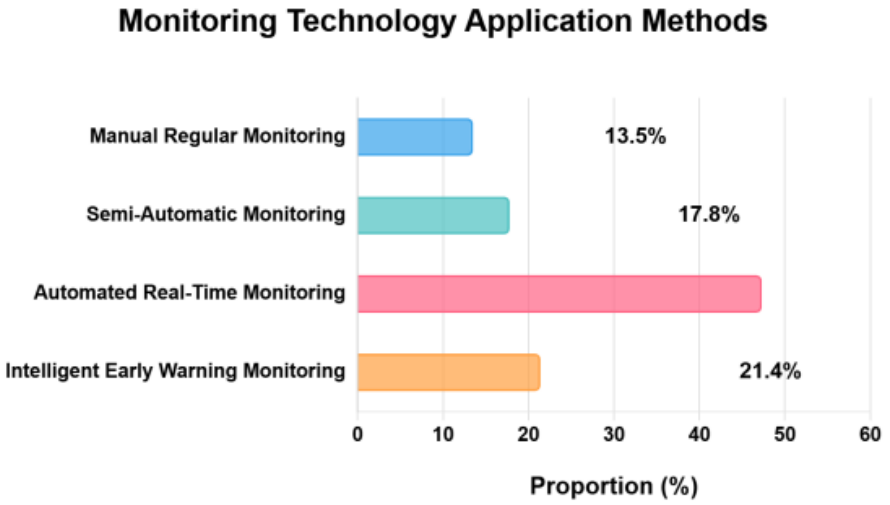

Fig. 2. Percentage of application methods of tunnel monitoring technology in China (2024)

The number of tunnelling projects in China has shown explosive growth in recent years, with the total mileage of road tunnels exceeding 19,000 km and railway tunnels reaching 16,500 km by 2024. Tunnel construction monitoring technology has developed rapidly, and the accuracy and stability of sensors have improved significantly. According to survey data from the Ministry of Transport, the tunnel monitoring automation rate reached 78.6% in 2022, an increase of 32.4 percentage points from 2018; the frequency of monitoring data collection was increased from the traditional 1-2 times per day to real-time monitoring, and the delay in data transmission was reduced to milliseconds. As shown in Table 1, indicators such as the monitoring automation rate and the application rate of remote real-time monitoring showed a rapid growth trend. However, the depth of monitoring data utilization is insufficient, with only 39.4% of projects realizing data mining analysis; the degree of monitoring standardisation is not high, with poor data compatibility between regions; the equipment failure rate averages 12.8%, affecting data continuity; and there is insufficient integration of monitoring and project management, with decision-making support capacity to be improved[4]. As shown in Figure 2, automated real-time monitoring and intelligent early-warning monitoring together account for nearly 70% of the total, indicating that automation and intelligence have become the mainstream technical direction of tunnel monitoring.

Table 1. Statistics on the development of tunnel construction monitoring technologies, 2018-2024

Indicator	2018	2020	2022	2024
Monitoring Automation Rate (%)	46.2	59.8	78.6	86.5
Remote Real-Time Monitoring Application Rate (%)	28.7	42.5	63.9	75.2
Integration of BIM and IoT Application Ratio (%)	22.3	38.6	56.7	68.9
Big Data Analytics Application Rate (%)	31.5	45.8	63.2	72.6
Monitoring Data Mining and Analysis Ratio (%)	18.6	27.3	39.4	48.7
Equipment Failure Rate (%)	24.6	18.2	12.8	8.3

4 Engineering Management Value System of Tunnel Construction Monitoring Data

4.1 The Value of Monitoring Data in Engineering Decision-Making

In the decision-making process of tunnel engineering, monitoring data plays the role of irreplaceable scientific basis. The construction team uses the surrounding rock deformation data to analyse the trend of geological conditions, adjust the excavation parameters and support scheme, and optimise the construction process. When a highway tunnel project crossed a fault zone, the displacement monitoring data showed that the rate of peripheral rock deformation exceeded the warning value, and the engineers immediately adjusted the excavation step length and initial support parameters according to the data analysis results, avoiding the potential risk of collapse[5]. The monitoring data also realised the dynamic balance between construction progress and safety risk, which cracked the limitations of traditional empirical decision-making. The tunnel information management platform integrates monitoring data, design parameters and construction information to build a digital twin model and realise visual decision-making support. The data-driven accurate decision-making effectively reduces human judgement bias, improves the scientificity of engineering decision-making, and shifts tunnel construction from the traditional ‘experience-led’ to ‘data-led’ mode.

4.2 The Value of Monitoring Data in Safety and Security

The tunnel safety guarantee system builds an all-round prevention and control network with the help of monitoring data. The real-time monitoring data of key parameters such as peripheral rock pressure, groundwater level, lining stress and so on form a tunnel safety ‘medical report’, revealing the health status of the project. During the construction of a long railway tunnel, the groundwater pressure monitoring system captured abnormal fluctuations in water pressure, 72 hours earlier than the regular inspection warning of the risk of water influx, the engineering department quickly implemented a pre-injection of grouting reinforcement in advance, and successfully avoided a large-scale water influx disaster. The safety management personnel established an early warning threshold system adapted to local geological conditions based on the analysis

of historical monitoring data, which increased the accuracy of early warning by 37%. The engineering case database formed by the accumulated monitoring data has become a valuable resource for safety management, supporting the identification of risk sources and the preparation of emergency plans. The perimeter rock stability assessment model was trained based on the monitoring data, realising intelligent safety status prediction, transforming passive response into active prevention and control, and significantly improving the safety management level of tunnel construction.

4.3 Value of Monitoring Data in Quality Control

Monitoring data provide an objective and quantitative basis for quality assessment in the quality control of tunnel projects. The secondary lining concrete shrinkage deformation and temperature field distribution data captured by the monitoring system guided the development of maintenance programmes and reduced the risk of lining cracking. The lining thickness monitoring of a mountain tunnel project found that the deviation of local sections exceeded the standard, and the quality management team used these data to pinpoint the problem areas and adjust the spraying process in time to ensure the structural safety reserve. The design unit analysed the results of the comparison between various types of monitoring data and design parameters, verified the accuracy of the calculation model, optimised the support parameters and structural dimensions, and improved the design economy. The monitoring data mining analysis revealed the intrinsic correlation between the construction process and quality defects, which helped the construction team to identify the weak points of quality control.

4.4 Value of Monitoring Data in Cost Management

In the field of tunnel project cost management, monitoring data has created significant economic benefits. The engineering management team optimised the support design based on the perimeter rock grading monitoring data, and a highway tunnel project precisely adjusted the sprayed concrete thickness and anchor density, which saved 2.15 million yuan in support material costs. The progress management system integrates construction monitoring data, dynamically adjusts the allocation of construction resources, reduces idle work and equipment, and improves the efficiency of resource use. In the process of claiming for engineering changes caused by abnormal geological conditions, the monitoring data become a powerful technical basis. A railway tunnel crosses the section of fault fracture zone, and the success rate of claiming for geological changes supported by the monitoring data reaches 92%, which effectively safeguards the legitimate rights and interests of the construction side. The monitoring data analysis during the tunnel operation period reveals the structural weak parts and deterioration laws, guides the maintenance plan formulation, changes the traditional cyclic maintenance into predictive maintenance, and reduces the whole-life maintenance cost by 32%, which realises the transformation from pure construction cost control to the optimization of the whole-life cost.

5 Conclusion

As the scale, complexity and technical difficulty of modern tunnelling projects continue to increase, so does the importance and management value of monitoring data. Traditionally, monitoring data have been regarded as a tool for safety warning, but now monitoring data play a crucial role in all aspects of tunnelling, including engineering decision-making, safety assurance, quality control and cost management. This study systematically analyses the value system of monitoring data and highlights how monitoring data can support real-time decision-making, improve construction accuracy, reduce risk and increase project efficiency. The transformation of monitoring data from a passive early warning signal to an active and comprehensive management resource marks a major leap in tunnel project management towards refinement and intelligence. In addition, this shift reflects the megatrend of data-driven construction, where the integration of digital technologies enables deeper insights and more proactive control throughout the project lifecycle. In order to realise the full potential of monitoring data, future efforts should focus on the standardisation of data formats, the development of advanced data mining and analysis techniques, and the seamless integration of monitoring systems with overall project management platforms. It is also crucial to develop interdisciplinary talent with expertise in both engineering and data analytics. Together, these initiatives will accelerate the process of engineering intelligence.

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