Life Cycle Management and Intelligent Maintenance Strategy of Urban Roads and Bridges

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Abstract: As the key infrastructure of urban traffic, the stable operation of urban roads and bridges is very important. This article focuses on the life cycle management and intelligent maintenance strategy of urban roads and bridges. This article analyzes the management points of each stage of life cycle, including planning, design, construction, operation and demolition, and designs and expounds the sensor layout, data analysis, decision-making model construction and implementation guarantee of intelligent maintenance strategy. Based on this, this article studies the technical, management system, cost-effectiveness and other challenges faced by their integrated development, and puts forward corresponding strategies. The research results show that the scientific design and implementation of clear management points and intelligent maintenance strategies in each stage is the basis for improving the management level of roads and bridges, and effectively coping with the challenges of integrated development is the key to realize the deep integration of the two. Finally, it is concluded that through systematic research and practice, the organic integration of life cycle management and intelligent maintenance strategy of urban roads and bridges can be promoted, and the safety, durability and management efficiency of roads and bridges can be improved.

1. Introduction

As a key component of urban infrastructure, urban roads and bridges play an important role in the economic development, residents' life and smooth transportation of the city [1]. With the acceleration of urbanization and the continuous growth of traffic flow, urban roads and bridges are faced with more complicated use environment and load conditions, and their performance and safety issues are increasingly concerned [2]. Ensuring the reliable operation of urban roads and bridges in the whole life cycle has become an important issue to be solved urgently in the field of urban construction and management [3].

The concept of life cycle management provides an effective way for the sustainable development of urban roads and bridges. It regards the whole process of road and bridge from planning and design to demolition as an organic whole, and comprehensively considers the interaction and function of each stage, aiming at realizing the optimal allocation of resources, effective cost control and long-term stability of performance [4-5]. With the help of advanced sensor technology, data processing technology and decision support system, intelligent maintenance strategy can obtain the state information of roads and bridges in real time, accurately evaluate their health status, and make scientific and reasonable maintenance decisions according to the evaluation results [6].

Scholars have done a lot of research on life cycle management and intelligent maintenance strategy of urban roads and bridges [7]. Part of the research focuses on life cycle cost analysis, and seeks the optimal cost management scheme by quantifying the costs at each stage. Some researches are devoted to the research and development of intelligent monitoring technology to improve the accuracy and reliability of monitoring data [8]. However, at present, there are still some shortcomings in the systematic management of each stage of life cycle and the deep integration of intelligent maintenance strategy and life cycle management.

Under this background, this study deeply analyzes the management points of urban roads and bridges at all stages of their life cycle, designs scientific and reasonable intelligent maintenance

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strategies, and explores effective ways to deeply integrate them. This study can enrich and improve the theoretical system of urban road and bridge management, provide practical management methods and technical support for practical projects, improve the management level and maintenance efficiency of urban road and bridge, prolong its service life and ensure the safe and stable operation of urban traffic infrastructure.

2. Analysis of management points in each stage of life cycle

In the planning stage of urban roads and bridges, relevant personnel need to accurately predict the growth trend of traffic flow. As an important basis for the design load of roads and bridges, the accurate prediction of traffic flow plays a decisive role in the safety and applicability of the structure [9]. Planners should fully consider the surrounding environmental factors, such as topography, geological conditions and climate characteristics, to ensure that roads and bridges are compatible with the surrounding environment. The design stage is the key link to determine the life and performance of roads and bridges. Designers should give consideration to durability and functionality, and choose a reasonable structural form according to the use requirements and site conditions of roads and bridges in structural selection to ensure that the structure has sufficient bearing capacity and stability. In terms of material selection, priority should be given to materials with good durability and stable performance to ensure the service life of roads and bridges from the source. The key point of management in the construction stage is to ensure the quality of the project. The construction team should strictly control the construction technology and operate according to the design requirements and construction specifications to ensure the quality of each process [10]. Quality inspection is indispensable. Through regular quality inspection and testing, quality problems in the construction process can be found and corrected in time, so as to avoid potential quality problems left over to the subsequent use stage. The core task of operation stage is maintenance management. Daily inspection work should be meticulous and comprehensive, and diseases and damages of roads and bridges should be found in time. For the problems found, managers need to arrange repairs in time to prevent the disease from developing further. Relevant departments should also establish a sound file management system to record the usage and maintenance history of roads and bridges, so as to provide data support for subsequent maintenance decisions. The demolition stage should follow scientific and reasonable principles and processes. Demolition work should ensure that it will not have adverse effects on the surrounding environment and other infrastructure, and at the same time realize the reasonable recovery and utilization of resources, minimize the damage to the environment and achieve the goal of sustainable development.

3. Design and implementation of intelligent maintenance strategy

Intelligent maintenance strategy aims at real-time and accurate monitoring and maintenance decision of urban roads and bridges through advanced technical means to ensure their safe and stable operation. The design and implementation of this strategy covers many key links. The first is the sensor layout and data acquisition scheme. In order to obtain the state information of roads and bridges in an all-round way, it is necessary to arrange all kinds of sensors reasonably. Strain sensors and displacement sensors are arranged at key structural parts, such as piers and girders of bridges and pavement base of roads, to monitor the stress, strain and deformation of the structure. Temperature sensors are arranged on the bridge deck to monitor the influence of temperature changes on roads and bridges. At the same time, consider setting humidity sensors on the road sections prone to water accumulation. Figure 1 lists all kinds of sensors and their applicable monitoring positions in detail. By scientifically arranging these sensors, an omni-directional data acquisition network can be formed, which can collect the state data of roads and bridges in real time and accurately.

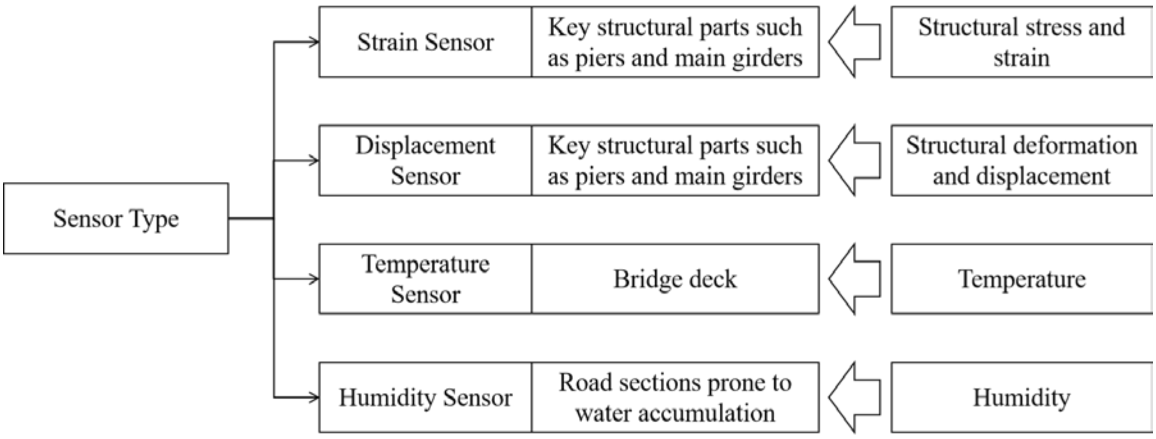

Figure 1 Sensor types and monitoring positions of urban roads and bridges

Data analysis method based on big data and artificial intelligence is the core of intelligent maintenance strategy. The collected data can only be converted into valuable information after professional processing and analysis. Using big data technology to store, manage and mine massive monitoring data, and analyze the potential relationship between the data. With the help of artificial intelligence algorithms-neural network, support vector machine, etc., the health assessment model of roads and bridges is constructed. These models can automatically identify the abnormal state of the structure according to the monitoring data, and realize the early warning of diseases.

The construction and application of intelligent maintenance decision model is the key to realize accurate maintenance. According to the data analysis results, combined with the design standards of roads and bridges, service life, traffic flow and other factors, an intelligent maintenance decision model is constructed. The model can automatically generate the optimal maintenance scheme according to the health status of the structure, including maintenance opportunity, maintenance measures and maintenance resource allocation. When the model judges that the bridge structure is slightly damaged, it is suggested to take preventive maintenance measures, such as sealing the surface in time; If the disease is serious, more complex repair schemes, such as structural reinforcement, are given.

The organization and management in the implementation of intelligent maintenance strategy are as important as the safeguard measures. Set up a special intelligent maintenance management team, which is responsible for coordinating all resources, ensuring the normal operation of sensors, effective data collection and analysis, and smooth implementation of maintenance decisions. At the same time, the government should formulate a strict data security management system to ensure the confidentiality, integrity and availability of monitoring data; Strengthen cooperation with relevant scientific research institutions and enterprises, introduce the latest technological achievements in time, and constantly optimize the intelligent maintenance strategy.

4. Challenges and coping strategies of integrated development

4.1 Technical challenges

Although the integration of life cycle management and intelligent maintenance strategy of urban roads and bridges brings new opportunities to improve the management level of infrastructure, it also faces many challenges in the actual process of promotion. The first problem is data compatibility. The data collected by different types of sensors and monitoring systems have different formats, accuracies and frequencies. Sensors used to monitor bridge vibration may collect data at high frequency, while equipment used to detect pavement smoothness may collect data at relatively low frequency. This makes data integration and analysis difficult. Table 1 visually presents the data differences of some common sensors. To solve this problem, it is necessary to develop a unified data conversion and preprocessing platform to convert all kinds of data into standard formats; Establish a data quality evaluation system to control the data quality in real time.

Table 1 Data Characteristics of Different Sensors

Sensor Type	Application Location	Data Format	Collection Frequency	Accuracy	Estimated Daily Data Volume	Data Transmission Protocol
Bridge Vibration Sensor	Connection between Pier and Main Girder	Binary	1000Hz	$0.01mm/s^2$	Approximately 1GB	TCP/IP
Pavement Evenness Sensor	Key Road Sections	Text	Once every 5m	0.1mm	Approximately 50MB	HTTP
Structural Strain Sensor	Main Stress Areas of the Bridge	Floating-point	10Hz	1με	Approximately 100MB	Modbus
Temperature and Humidity Sensor	Bridge Deck and Low-lying Areas of the Road	Integer	Once per minute	Temperature ±0.5℃, Humidity ±2%RH	Approximately 20MB	MQTT
Crack Width Sensor	Crack-prone Areas	Digital	Once every 10min	0.01mm	Approximately 15MB	CoAP

Life cycle management involves many links, such as planning, design, construction and operation. The software system used in each link is different from the management platform, so it is very difficult to realize the seamless integration of intelligent maintenance strategy and these links. In this regard, departments should formulate unified system integration standards and interface specifications, and clarify the data interaction methods and processes between systems. Middleware technology is adopted to realize data sharing and business collaboration between different systems.

4.2 Management system challenges

Poor coordination among departments is a prominent problem in the management system. The planning, construction, operation and maintenance of roads and bridges belong to different departments, and the focus and objectives of each department are different. The planning department focuses on the long-term development layout, while the operation department pays more attention to the current maintenance cost and safety. This difference easily leads to poor information circulation and poor work connection. To solve this problem, it is necessary to establish an inter-departmental coordination mechanism and set up a special coordination agency or group to coordinate the work of various departments. Hold regular inter-departmental meetings, strengthen information communication and sharing, and ensure that all departments work together in the integration of life cycle management and intelligent maintenance. At present, the relevant standards and specifications for the integration of life cycle management and intelligent maintenance strategy are not perfect, which makes the actual operation lack clear guidance. There is a lack of unified regulations on the evaluation criteria of intelligent monitoring data and the basis for making maintenance decisions. Therefore, we should speed up the formulation and improvement of relevant standards and norms. Led by the competent department of industry, organize scientific research institutions, enterprises and other relevant units to formulate standards and specifications covering the whole process of data collection, analysis and maintenance decision-making in combination with actual engineering experience and technology development trend.

4.3 Cost-effectiveness challenge

Large upfront investment is the primary challenge in terms of cost-effectiveness. The implementation of intelligent maintenance strategy needs to purchase a large number of advanced sensor equipment and build a data processing platform, and the optimization of life cycle management also needs to invest more manpower and material resources in planning and research.

Take a medium-sized bridge as an example, if a complete intelligent monitoring system and supporting data processing facilities are installed, the initial investment may be as high as several million yuan. In order to alleviate the financial pressure, this article thinks that we can adopt a diversified investment model with government guidance and social capital participation. Through policy support, attract enterprises, financial institutions and other social forces to participate in the construction and maintenance of road and bridge infrastructure.

The life cycle of roads and bridges is long, and the benefits brought by the integration of intelligent maintenance and life cycle management may be difficult to reflect in the short term, which makes investors' enthusiasm frustrated. In this regard, relevant departments should establish a reasonable cost-benefit evaluation system, which not only pays attention to short-term economic benefits, but also evaluates long-term social benefits and environmental benefits. Through quantitative analysis, investors can clearly understand the long-term value of integrated development and enhance their investment confidence.

5. Conclusions

This article focuses on the life cycle management and intelligent maintenance strategy of urban roads and bridges and their integrated development. In the analysis of management points in each stage of life cycle, it is clear that planning needs to accurately predict traffic flow and adapt to the surrounding environment; Design should give consideration to durability and functionality; Construction focuses on ensuring the quality of the project; Operation emphasizes daily inspection and disease repair; Demolition follows scientific principles to realize rational utilization of resources. In the aspect of intelligent maintenance strategy, through reasonable sensor layout and data collection, combined with data analysis of big data and artificial intelligence, an intelligent maintenance decision-making model is constructed and applied, and at the same time, organizational management and safeguard measures are strengthened to provide scientific basis for road and bridge maintenance. However, the integration of the two faces many challenges. Technically, data compatibility and system integration complexity hinder data integration and system collaboration. In the management system, poor coordination between departments and lack of standards and norms affect the work progress. In terms of cost-effectiveness, large initial investment and long investment return period inhibit development enthusiasm. In view of these challenges, this article puts forward corresponding strategies, including developing a unified data platform, formulating system integration standards, establishing an inter-departmental coordination mechanism, improving standards and norms, adopting diversified investment models and establishing a reasonable cost-benefit evaluation system.

The integrated development of life cycle management and intelligent maintenance strategies for urban roads and bridges is an inevitable trend to improve the management level and maintenance efficiency of urban roads and bridges. Although facing many challenges, through effective coping strategies, we can realize the deep integration of the two, ensure the safe and stable operation of urban roads and bridges in the whole life cycle, and promote the sustainable development of urban infrastructure construction.

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