An Analysis of Intelligent Operation and Maintenance for Rail Transit Electric Locomotives

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Abstract

The transportation capacity pressure and the high technological content of rail transit equipment make safety control problems potentially disastrous. These challenges elevate demands for the development of intelligent technology in the field of rail transit operation and maintenance, allowing significant room for growth and development in the industry. This paper reviews the current status of intelligent operation and maintenance by discussing the intelligent operation and maintenance detection of locomotives and the electric locomotive technology state management platform in rail transit. Through an analysis of locomotive operating data acquisition, the architecture of the intelligent monitoring and maintenance system, key factors affecting fault diagnosis and remote operation and maintenance, and intelligent operation and maintenance systems, this paper summarizes the current state of intelligent operation and maintenance.

Keywords

Rail transit, Intelligent operation and maintenance, Electric locomotive

1. Introduction

Rail transit is currently experiencing a phase of rapid development through high-speed construction. This trend has created vast opportunities in rail transit maintenance [1]. Nevertheless, the safety monitoring and maintenance for rail transit has yet to achieve full integration of information technology and artificial intelligence. This is partly due to the progress made in rail transit construction, the growing train fleet, and the increase in the application of electric locomotives, which collectively have caused the number of trackside facilities to surge. Consequently, the technology employed in facility systems within these facilities is highly complex and of a large scale, making maintenance more challenging. Rail transit, on the other hand, is known for its capacity as a secure and independent mode of transportation. But the high demand for capacities in rail transit, alongside the technology-intensive equipment, pose disastrous outcomes when control fails. These challenges necessitate a need for intelligent technology development concerning rail transit maintenance, while creating substantial growth opportunities for the rail transit management and maintenance sector. Rail transit is composed of multiple sub-systems: infrastructure, vehicle servicing, station servicing, and other interrelated systems. The maintenance of electric locomotives occupies a vital position among all other systems [2].

The operation route scale of rail transit is exhibiting a trend of gradual expansion. However, this comes hand in hand with an increasing pressure on operation and maintenance due to the progressively growing network structure. As rail transit networks continue to expand, the facility scale also grows. The facility equipment system is under significant duress, leading to new requirements in the development of monitoring and maintenance. Moreover, the advent of the intelligent era brings about a transformation: intelligent electric locomotives, with a primary focus on large-capacity and long-distance, will become the principal vehicle. In turn, this will enforce requirements for the intelligent operation and maintenance system of vehicles. The intelligent operation and maintenance system of vehicles is usually split into three parts: vehicle interconnection system, trackside vehicle comprehensive monitoring system, and train operation trajec-
tory system. In summary, rail transit is characterized by typical equipment facility resource-intensive conditions, with a large number of associated disciplines. Following scientific and sound intelligent operation and maintenance standards is a crucial aspect in ensuring the efficient and normal working conditions of electric locomotives, and to maintain a safe, seamless, and cost-effective operation in rail transit [3].

2. Current Status, and Intelligent Operation and Maintenance for Electric Locomotives in Rail Transit

Electric locomotives currently serve as the primary source of power for rail transit. Due to their robust performance, they have been widely used and extensively developed, particularly for routes that feature high train frequency, busy schedules, and high traction demands. However, combining high equipment technology requirements with limited capacity for natural disaster response and large investment needs, electric locomotive monitoring, operation and maintenance pose significant challenges. The ultimate objective of smart monitoring, operation, and maintenance is to ensure the safety and stability of rail transit equipment while maximizing cost savings. In this context, accurate application and on-demand maintenance represent core and key components of intelligent operation and maintenance. Within China, current management approaches for electric locomotives predominantly rely on traditional methods that necessitate substantial human and material resources while manifesting poor work efficiency. These inefficient practices hinder the ability to make accurate and scientific assessments of electric locomotive operation status and use, or to effectively monitor the quality and conditions of electric locomotives while entering or during service. As electric locomotive monitoring technology and information technology continue to advance, emphasis is shifting towards digitally-based, networked, and intelligent-based approaches to electric locomotive maintenance and operation to address the deficiencies of traditional wear theory-based preventive repair systems. More specifically, the trend is now towards on-demand maintenance systems based on an actual loss assessment approach.

2.1 Intelligent Detection of Electric Locomotives

Electric locomotives feature three main construction parts: electrical, mechanical, and air pipeline systems that comprise electrical equipment, wiring, running gear, vehicle bodies, and air supply systems for a variety of devices. These components allow electric locomotives to have high pulling force, low self-weight, fast speeds, high efficiency, and to be environmentally friendly. The safe functioning of electric locomotives also depends on the high-tech and financial help provided for electrified railway system establishment, advanced electric locomotive research and development, and equipment operation and maintenance due to the electric power delegation received by the power grid and the power rails running along the rail track. Consequently, the effective, precise, and safe monitoring of electric locomotives, especially via intelligent machines, is paramount for opportunities to ensure that these electric locomotives operate dependably and receive regular maintenance support. The employment of electric locomotives' constructive amalgamation of an intelligent comprehensive monitoring system and preventive maintenance inter-connected monitoring system helps maintain stable electric locomotive performance and manage and analyse the functioning of critical electric locomotive parts. This system also delivers early warnings of potential accidents and graded alert levels and maintains smart vehicle conducting to ensure consistent safety and stable vehicle operations [4].

In the construction of electric locomotive intelligent monitoring systems, the research on the intelligent operation and maintenance of electric locomotives aims to use a scientific monitoring system to achieve analysis and evaluation of the system, in order to achieve the goal of intelligent operation and maintenance management. This monitoring system includes a mainline dynamic comprehensive monitoring system that is directly installed on the operating line, meets the monitoring requirements of operating dynamics, and monitors key operating conditions and data to effectively reduce the risk of accidents. Also, an entry line comprehensive monitoring system that is directly placed at the entryway of the operating line, conducts systematic and comprehensive monitoring management based on the specific operating condition of equipment in the electric locomotive, ensuring the comprehensive monitoring of the entry line and secure operations of rail transit. Moreover, a depot deep monitoring and control system containing a mobile axle ultrasonic flaw detector, automated robots for depot intelligent inspection, and other facilities is included in the monitoring system.

In the context of electric locomotive intelligent monitoring systems, rail transit technology has gradually advanced from the stage of high-speed development to the stage of deep intelligent new technology development. The rise of fully automated operation and maintenance services has also put forward targeted demands for enhancing the intelligent monitoring and maintenance capabilities. At this stage, the following technological foundations need to be established: intelligent collection, localization, and monitoring of large-scale industrial data; IOT technology for visualization control and remote monitoring; edge computing and cloud computing technologies for addressing data sharing issues; artificial intelligence and big data technologies for collecting, analysing, tracing, and troubleshooting the large amount of data generated during the operation of transportation signals, systems, and devices.
2.2 Technical Status Management Platform for Electric Locomotives

Considering the highly integrated technological and complex structural characteristics of electric locomotives, managing the technical status and information of electric locomotives and its components effectively throughout its full life cycle, from product design to operation and maintenance, is crucial [5]. Creating a big data analysis platform for technical status and management enables correlation analysis of technical status information during the various phases of the full electric locomotive life cycle, resulting in the integration of manufacturing, maintenance, and usage data of locomotives. Moreover, the deep analysis of big data, along with the development of a self-generated comprehensive information management system that encompasses the entire value chain, leads to the provision of a fundamental database for large-scale data mining in enterprise operation and maintenance.

The establishment of the Technical Status Management Platform for Electric Locomotives focuses on constructing an information system for the management and tracing of the full life cycle (as illustrated in Figure 1) of electric locomotives. This is accomplished by integrating information systems from the product design, production, operation, and maintenance stages and connecting the digital information platforms of relevant products to form a traceability system for the full life cycle of electric locomotives and their components. Thus, an information-sharing platform is established to enable the tracking and analysis of the quality of electric locomotives and their components throughout the full life cycle. During the product design and development stage, the main management components of electric locomotives are identified throughout their full life cycle. The supervision and data analysis of the full life cycle information are performed by accumulating product information and tracking production data of typical components, electric locomotives, and systems to identify and address problems in various stages of design, production, monitoring, and operation-maintenance. By enabling design departments to take advantage of their unique technological resources, the establishment of the Technical Status Management Platform for Electric Locomotives further enhances the quality of intelligent operation and maintenance services [6].

Figure 1. Full life cycle of rail transit electric locomotive.

2.3 Intelligent Application of Electric Locomotive Monitoring, Diagnosis and Maintenance

Electric locomotive data is complex and multifaceted, requiring specialized knowledge and closely tied to business operations. Faults may also be diverse in nature. The traditional monitoring and maintenance management model has been shown to be inadequate in meeting the needs of modern technology, including project operating cost, product manufacturing cycle, and production service quality. Implementing intelligent electric locomotive monitoring, diagnosis and maintenance applications allows for real-time monitoring of production conditions and efficient resource management through comprehensive data utilization and precise product detection management [7]. The automated system will be built on existing data systems, and utilize digital products and big data integration to overcome information barriers and reduce unique instability factors in electric locomotive detection. This will lead to the digitalization, networking, and intelligence of the detection system, thereby improving pre-prevention and process tracking of product quality risks and enhancing the reliability and efficiency of product quality testing.

Electric locomotive operation data is collected by on-board terminals and transmitted to the ground using various communication methods. The collected data includes information on electric locomotive operation, critical equipment component status, and events, such as current location, speed, ambient temperature, rotational speed, power, voltage, fault alerts, and other data. The collected data is promptly transmitted to relevant personnel, who use it to guide operational and maintenance staff in detecting and addressing faults, thereby ensuring the safe operation of electric locomotives.
The electric locomotive monitoring, diagnosis and maintenance intelligent application consists of several layers, including smart equipment, intelligent sensing and control, decision-making, and implementation layers. This system enables real-time monitoring and intelligent interconnection of production equipment, facilitating unified collaborative monitoring, scheduling, and operational management. The system also improves the timeliness and accuracy of data collection and application, facilitating real-time information collection, monitoring, and transmission. Furthermore, this system enables timely implementation of production guidance strategies and responses to major events, improving responsiveness and effectively optimizing production guidance. The system promotes resource allocation awareness among various subsystems, providing necessary resources for the effective implementation of production planning and enabling production management personnel to self-assist in setting strategic goals.

Based on the established work procedure, a fault management database has been created for electric locomotive fault diagnosis and remote operation and maintenance. The database utilizes the fault model, the fault generation process and results of significant components, system attribute anomalies, alarm conditions, as well as the association between the fault tree and failure models. In addition, exceptional models were analyzed using the knowledge graph, and after feature learning based on normal and abnormal data, relevant classification characteristics were studied to clarify the relationship between faults and events. Based on the analysis, a fault mechanism model was established for fault analysis.

To implement the intelligent application of electric locomotive operation and maintenance, several critical factors should be considered. Firstly, technical status information on vital components must be collected throughout the entire locomotive testing process during data collection. Big data and data mining techniques should then be employed to analyze and investigate this information, providing insights into warning signs, risks, technical issues and status of key components [8]. Secondly, enterprise service bus technology should be used to integrate various manufacturing resources in the enterprise network system and exchange information flows within the enterprise system. Furthermore, it is essential to establish an enterprise resource cooperation management cloud platform capable of forming intelligent services based on big data processing to achieve effective network collaboration with production in different regions or external enterprises. Integration of various software and hardware resources should also be done to optimize resources allocation. This approach facilitates smart decision-making support for railway product design, development, manufacturing, management, operation and maintenance, information services while achieving networked resource collaboration management.

3. Prospects for Intelligent Operation and Maintenance of Rail Transit

The rail transit industry is an example of a sector with a high investment in equipment and facilities, particularly in monitoring and maintenance aspects. This industry involves numerous disciplinary fields and is characterized by a substantial amount of equipment and facilities. Following standardized and intelligent operation and maintenance guidelines is essential to ensure the safe, stable, and efficient economic operation of rail transit facilities. However, rail transit operation and maintenance face various challenges, including significant discrepancies in the level of informationization between operation and maintenance with comprehensive management of lines and systems. There is a lack of a unified standard for operation and maintenance management systems, insufficient security and integrity measures for data transmission between vehicles and the ground, and difficulties in realizing interconnectedness and interoperability of equipment data due to the separate operation and maintenance management systems created by distinct rail transit professionals. These problems hinder the support of multi-disciplinary correlation analysis.

The development of modern rail transit has increased demands for reliable, stable, maintainable, and safe electric locomotive operations. The integration of advanced technologies such as artificial intelligence detection and control, cloud computing, and big data analysis in an intelligent management and operation system can efficiently analyze a large amount of operation and maintenance information, conduct deep data mining and artificial intelligence calculation, and achieve full lifecycle control of the infrastructure to automate management and maintenance. In the future, intelligent management and operation systems of electric locomotives will focus on improving safety during operation, vehicle stability, detection effectiveness, and operation and maintenance quality. These efforts aim to reduce manpower investment and management costs while assuring safe, efficient vehicle operation. As intelligent rail transit operation and maintenance develops rapidly, early adoption and implementation of intelligent operation and maintenance in various stages can ensure independent research, development, and manufacture of rail transit intelligent operation and maintenance technology. Forming an efficient system structure under the rail transit big system will help seize new technology and management opportunities, and effectively improve the level of intelligent operation and maintenance.

References


