Research on Reliability Evaluation Method of Urban Rail Transit Train System

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ABSTRACT. *In view of the lack of unified standards for the reliability evaluation of urban rail transit system in China, based on the safety and reliability of system, network theory, fault propagation, operation and maintenance optimization and other related theoretical knowledge, and combined with the actual operation conditions, this paper makes in-depth analysis and research on the safety reliability and availability of urban rail transit operation, a set of evaluation process and method for the reliability and availability of urban rail train system is established. According to the evaluation results, the relevant departments of urban rail train are guided to control or eliminate the possible faults or accidents of the system, predict the future safety conditions, ensure the safety reliability and availability of urban rail train operation, so as to achieve the purpose of reducing accident rate and loss.*

KEYWORDS: *Urban rail transit train, Fault propagation, Reliability of system operation*

1. Introduction

With the development of urban rail transit, as the most important tool and direct carrier to complete the transport task, the demand of urban rail train is increasing rapidly. With the increase of the number of urban rail trains, how to accurately grasp and analyze the safety reliability and availability of the key equipment and the overall system of the train is the focus of current research and the most urgent problem faced by the urban rail transit department.

At present, the methods of train reliability design and analysis are not in-depth enough, and the limitations of the methods are still large. Overseas researches on the reliability of rail transit system mainly focus on reliability index [1], reliability analysis and processing [2], reliability of train subsystem [3], etc. In China, the research on reliability analysis of rolling stock is mostly carried out, such as failure data reliability statistical analysis based on failure [4], local strain reliability method [5], failure rate correlation model and prediction model. The reliability of the train subsystem is studied, for example, the fatigue life and reliability analysis of bogie and running system [6]; the reliability evaluation method of fault tree [7] and event

tree [8] for catenary system; the reliability evaluation research of fault mode impact analysis [9] and reliability block diagram for traction power supply system [10]. At home and abroad, the research and development of fault diagnosis and alarm of some equipment of urban rail train and maintenance management information system of urban rail train have been carried out successively, but the reliability design and analysis of the whole train system, as well as the research of availability evaluation method, are not available for the overall reliability analysis and life prediction of all systems, subsystems and components of the whole train. Therefore, on the basis of investigation, absorption and reference of relevant experience at home and abroad, based on the actual situation of urban rail train operation, we systematically carry out the research of train reliability evaluation method, and establish a standardized evaluation system of urban rail train system reliability and availability for the design, manufacturing, operation and maintenance departments of urban rail train. It plays an important role in the safe operation of the train, improving the reliability and availability, providing decision support for the optimization of the train maintenance strategy, and reducing the maintenance cost of the operation.

2. Related Definitions of Urban Rail Train Reliability

According to EN50126,GB/T 21562-2008 and other relevant standards and the actual conditions of urban rail transit operation, the concept of urban rail train reliability is defined firstly.

(1)*Train reliability:* This refers to the ability of the rail train system and its components to complete passenger transport service within the specified time under the specified conditions. The higher the reliability of the system, the less the possibility of failure and the greater the possibility of completing the specified function.

(2)*Operation safety of urban rail train:* This refers to the ability of urban rail train and its components not to cause damage risk during operation.

(3)*Operation reliability of urban rail train system:* This paper defines it as the ability of urban rail train and its components to complete the specified tasks or functions under the specified operation conditions and during the operation period.

(4)*Availability of urban rail train system*: This refers to the probability that the urban rail train and its components can perform the specified functions under the specified operation conditions and during the operation period.

(5)*Urban rail train failure:* This refers to the failure of the product during the normal operation of the train. Including:

①*Offline fault of passenger clearing:*This refers to the fault that the product fault causes the train unable to maintain the commercial operation or has a great impact on the commercial operation.

②*The delay fault:* The train stops on the line for more than 2 minutes due to the

fault, or has a great impact on the commercial operation.

③*Maintenance fault, odd repair, train inspection fault:* Vehicle fault found by the driver and fault found in the inspection of maintenance personnel.

3. Safety Reliability and Availability Assessment Process of Urban Rail Train Operation

The evaluation of the operation safety reliability and availability of urban rail trains is conducive to a deeper understanding of the faults and dangers affecting the operation of urban rail trains, and lays a foundation for the safe and reliable operation of urban rail trains.

The operation safety reliability and availability evaluation of urban rail train is a complete closed-loop process composed of the description and record of urban rail train fault, safety reliability analysis of urban rail train parts, failure propagation analysis of urban rail train system, operation reliability assessment of urban rail train system, availability assessment of urban rail train system, application and detection of safety reliability of urban rail train operation, as shown in Figure 1.
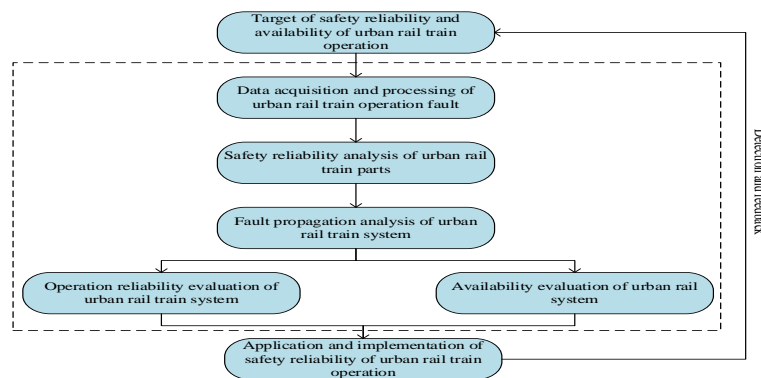

Fig.1 Flow Chart of Safety Reliability and Availability Assessment of Urban Rail Train Operation

(1)*Data acquisition and processing of urban rail train operation fault:* This module is the basis of safety reliability and availability evaluation of urban rail train operation, and it needs standardized description and record of urban rail train operation fault data. The main content of fault data description is fault mode, and the common fault mode analysis methods are Failure Mode and Effect Analysis (FMEA) and Criticality Analysis (CA).

(2)*Safety reliability analysis of urban rail train parts:* The purpose of this module is to understand the design life of parts or the time interval between failures, and to provide basis for the operation safety and reliability analysis of urban rail

train system. In the reliability analysis of parts and components, the material performance, environment, load effect and other factors shall be considered, and the corresponding reliability test or calculation shall be carried out to obtain the dynamic changes of reliability and failure rate of parts with time.

(3)*Fault propagation analysis of urban rail train system:*The technical composition of urban rail train is highly complex, which will produce the effect of fault propagation in case of fault, so it is very necessary to analyze the fault propagation. Fault propagation analysis can use fault tree analysis, Petri net and other methods to simulate the process of system fault propagation, or use complex network, virus propagation and distribution diffusion and other related theories to analyze the whole system fault propagation process.

(4)*Operation reliability evaluation of urban rail train system:* In the process of fault propagation of urban rail transit system, there is communication and transmission of information and materials in the system network. In the process of continuous transmission of these materials, the whole network may be affected, which is called disturbance. Based on the theory of complex network, this paper studies the topological structure of complex network to understand the internal dynamics of network behavior, constructs the system fault propagation model, and characterizes the operation reliability of urban rail train system by measuring the change of disturbance value of urban rail train system before and after fault propagation.

(5)*Availability evaluation of urban rail system:* This module is based on the system maintenance optimization to analyze and evaluate the availability of the whole train system. It should consider the complex structure between the train system and the complex relationship between the components and the system. Under the premise of ensuring reliability, we can consider the requirements of economy and timeliness, and optimize the maintenance mode and time of multi-component system. The common methods are group maintenance and opportunity maintenance.

(6)*Application and implementation of safety reliability of urban rail train operation:* According to the results of safety and reliability evaluation of urban rail train operation, safety countermeasures or rectification measures are proposed for the part of the system that fails to meet the requirements, and continuous inspection and supervision are carried out for the train, and relevant information of safety and reliability evaluation is updated in time. At the same time, monitor the effect of safety and reliability evaluation application of urban rail train, so as to provide basis for the improvement of safety and reliability evaluation of subsequent urban rail train operation.

In view of the above six steps, we focus on the study of urban rail train system fault propagation and operation reliability evaluation methods, which will be described in detail below.

4. Fault Propagation Analysis of Urban Rail Train System

4.1 Summaries

Based on the network structure of the system, the state of the node itself and its internal mechanism, combined with the knowledge of virus propagation and the theory of fault potential field, the fault propagation model of urban rail system is constructed. According to the principle of distribution and diffusion, the whole process of system fault propagation is analyzed, and all possible propagation paths and their probabilities are obtained, which provides theoretical support for the key maintenance tasks of field operation and maintenance personnel.

4.2 Fault Propagation and Fault Path Generation of Train System Based on Fault Potential Field

Based on the calculation of the failure rate of each component of the urban rail train in a certain period of statistical time, and the construction of the fault causal network between the components of the urban rail train system, the fault propagation and fault path generation of the train system based on the fault potential energy field are analyzed by the following steps:

(1)This paper studies the coupling relationship between urban rail train system and its components. The complex network model of urban rail train system is constructed by using complex network theory and graph theory, with components as nodes and components coupling relationship as connecting edge.

(2)Based on the complex network model of urban rail transit system, combined with the knowledge of virus propagation and the theory of fault potential field, the propagation probability model between components of urban rail transit system is constructed.

(3)Based on the initial state of urban rail system network and the propagation probability model between system components, and combined with the principle of distribution and diffusion, the whole process of system fault propagation is analyzed, and the failure propagation model of urban rail system is constructed.
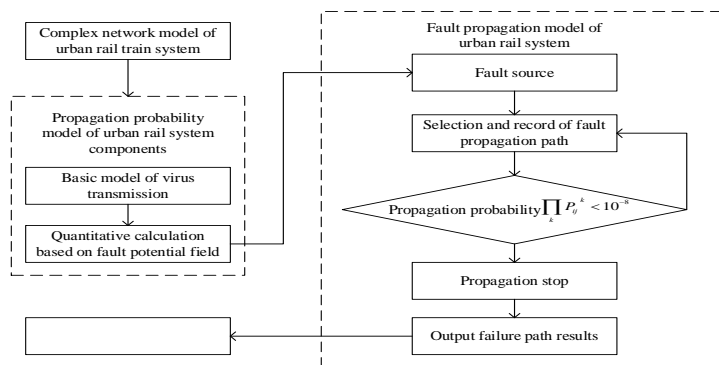

Fig.2   Fault Propagation and Fault Path Generation of Train System Based on

Fault Potential Field

Through the above analysis, the propagation path of urban rail train system in a certain period of statistical time, and the most likely fault chain and fault network between urban rail train systems in a certain period of statistical time can be obtained.

## 5. Operation Reliability Evaluation of Urban Rail Train System

5.1 Summary

The operation reliability evaluation of urban rail train system is a measure of the ability of the urban rail train system to complete the specified tasks or functions, or the probability of maintaining a certain performance under a specific operation condition and during the operation period. On the basis of train system fault propagation, the operation reliability evaluation of urban rail train system is characterized by measuring the change of network efficiency of urban rail train system before and after fault propagation.

5.2 Reliability Evaluation Method of System Operation

Based on the results of fault propagation analysis, the operation evaluation of urban rail train system is carried out based on system fault propagation and network efficiency. Based on the characteristics of the urban rail train system, a reliability evaluation model of multi-state system based on network flow theory is constructed. This method is based on the train system structure and the state of the system components, and calculates the transmission probability of the system network under a certain d-flow demand. Take the bogie system as an example to analyze the evaluation method.

Based on the topological structure of bogie system based on force transfer, the reliability evaluation model of bogie system is constructed, as shown in Figure 3.
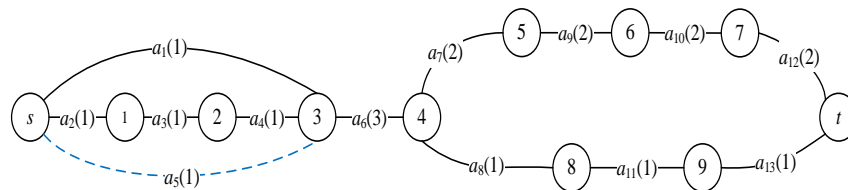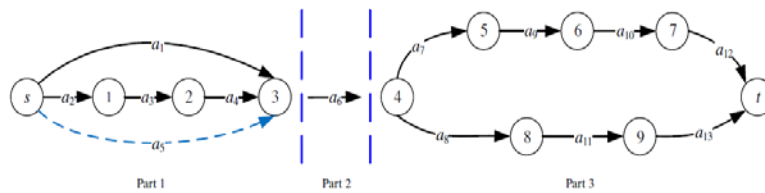

Fig.3 Reliability Evaluation Model of Bogie System

Among them,

(1)a_1: Braking device

(2)a_2: Traction motor

(3)a_3: Gearbox

(4)a_4: Coupling

(5)a_5: Rail

(6)a_6: Wheel

(7)a_7: Longitudinal force and vertical force transmission axle box

(8)a_8: Transverse force drive axle box

(9)a_9: Primary suspension device

(10)a_{10}: Longitudinal force and vertical force transmission axle box bogie

(11)a_{11}: Transverse force transmission axle box bogie

(12)a_{12}: Traction rod

(13)a_{13}: Air spring

(14)s: Starting node

(15)t: Target node

(16)*Nodes 1 to 9:* Correlation between system components

According to the established model, the steps to evaluate the reliability of the bogie multi- state system based on the network flow theory are as follows:

(1)The reliability evaluation model of bogie multi state system based on network flow theory is divided into three parts, as shown in Figure 4.

Fig.4 Division Diagram of Reliability Evaluation Model of Bogie Multi-State System

(2)Search all possible integer d values and all corresponding d-flow.

(3)Based on the Recursive Sum Algorithm for Disjoint Products (RSDP), the probability of the union of system network vectors is evaluated, and the components of system network are sorted by the heuristic algorithm by sorting variables.

(4)Evaluate the d-flow probability of system network, i.e. network reliability.

6. Conclusion

In view of the lack of unified standards for the reliability evaluation of urban rail train system in China, based on the demand investigation of the design, manufacturing, operation and maintenance departments of urban rail train, and based on the relevant theoretical knowledge of system safety reliability, network theory, fault propagation and operation and maintenance optimization, we propose an evaluation process of train operation reliability and availability. In this paper, we also analyzes the fault propagation method and operation reliability evaluation method of urban rail train system, and forms the method and standardized system that can evaluate the safety reliability and availability of urban rail train system systematically, reasonably and objectively, which is of great significance to meet the goal of safe and efficient operation of urban rail train.

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