Research on Quick Inspection Technology for the Auxiliary Brake of Escalators Based on Inventory

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Abstract: In this article, the structural characteristics of the auxiliary brake are analyzed, and fault data is statistically analyzed to obtain the risk points of the elevator's auxiliary brake. We obtained the weights of each risk factor through the Analytic Hierarchy Process and established an algorithm model for the risk of auxiliary brakes on escalators. Based on the concept of simple, reliable, and effective inventory management, a fast inspection method for auxiliary brakes based on inventory management has been established. This method can effectively inspect the additional brakes of escalators and can also be applied to the quality inspection of the working brakes of elevators and escalators, which has reference significance for the inspection of other complex equipment.

Keywords: Auxiliary brake, Escalators, risk, weight, Inventory management

1 Introduction

It is a safety protection device that must be installed on escalators in public transportation, and it is the last line of defense to guard escalator accidents. In recent years, multiple escalator accidents have been related to the ineffective action of the auxiliary brake. In December 2010, an escalator accident on Shenzhen Metro Line 1 resulted in 24 injuries; In July 2011, an escalator accident on Shenzhen Metro Line 4 resulted in 4 injuries; In the same year, the "7.5 accident" on Beijing Metro Line 4 resulted in one death and 30 injuries. The occurrence of these accidents has raised the issue of escalator safety, including the issue of auxiliary brakes on escalators, to an unprecedented level, and its safety has become a focus and hotspot of people's attention.

The auxiliary brake directly acts on the non friction components of the step and pedal drive system, effectively slowing down and stopping the escalator while maintaining a stationary state. When the driving chain is broken or the driving device is shifted, the working brake cannot be activated, and the escalator shows a reverse trend. At this time, the anti reverse protection switch action triggers the working brake and auxiliary brake. However, since the working brake is no longer functional, reliable braking of the auxiliary brake is necessary to stop the reverse or overspeed escalator.[1]

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2 The risk of adding brakes to escalators

During the survey, it was found that there are currently 4000 escalators in Beijing Subway, including more than ten elevator brands including SCHINDLER, Thyssen, Otis, Xizi Otis, Kone, Mitsubishi, etc. The brands are diverse and the types are complex. The escalators are connected to the step drive devices using various types such as shafts, gears, multi row chains, or multiple single row chains. Many brands of escalators have hidden installation positions for their auxiliary brakes, making it inconvenient for maintenance operations. At the same time, some installation and maintenance personnel lack understanding of the auxiliary brakes. In addition, when some escalators operate and stop normally, the auxiliary brake does not participate in the operation, which often leads to the neglect of the auxiliary brake during maintenance and inspection. The main problems identified during the random inspection and safety assessment of 6000 public transportation escalators in Beijing include: inadequate management by the user units; Component failure and untimely maintenance; Wear or aging of components; Not conducting regular inspections and adjustments according to maintenance requirements.

2.1 Manufacturing and maintenance

In terms of standards, GB16899-2011 "Safety Code for the Manufacturing and Installation of Escalators and Moving Walkways" states that manufacturers and owners should determine load conditions and additional safety functions based on actual traffic flow, but does not specify how to determine load conditions and additional safety functions[2]. In practice, manufacturers and owners will not propose additional technical requirements, Obviously, it cannot meet the requirements of long-term heavy load and high braking reliability of public transportation escalators. In the use and maintenance process, the Beijing local standard DB11/T 705-2019 "Technical Requirements for Heavy Duty Escalators and Traveling Walkways" specifies the basic requirements, requirements, tests, and inspections of heavy duty escalators and moving sidewalks, but does not mention the maintenance, inspection, evaluation, methods, and project content of auxiliary brakes[3].

2.2 Experiments and inspections

In terms of regular inspection, the effectiveness of the auxiliary brake is generally tested on site. The inspection method is carried out by the construction unit according to the method provided by the manufacturer, and the inspection personnel observe and confirm on site. Not all manufacturers have their auxiliary brakes subjected to functional testing at the factory, and it cannot be guaranteed that they will be fully effective in the place of use after transportation and installation. The auxiliary brakes found during the acceptance inspection of a certain subway were unable to stop the fully loaded down escalator, due to the lack of adjustment and testing after installation. Since 2013, Beijing has required all public transportation escalators to undergo a full load brake and auxiliary brake test during the acceptance process, which must be signed and confirmed by the relevant parties involved in the acceptance. In the experiment, it was also found that under the rated speed of full load, the auxiliary brake had wear, and a considerable number of auxiliary brakes had a relatively short lifespan. After three to five actions, the friction pair suffered severe wear and deformation.

3 Inventory management in escalator operations

Inventory management is a management method based on risk assessment and prevention. It requires a detailed risk assessment of each component of the escalator and the development of corresponding safety operation and maintenance procedures based on the assessment results. By establishing a list, categorizing and labeling each part, it is possible to ensure the correct operation and use of operators and maintenance personnel.

In addition, inventory management can also help identify and correct system defects. By regularly inspecting and maintaining various parts of the escalator, potential problems can be identified in a timely manner and measures can be taken to solve them, thereby avoiding safety accidents caused by system defects.

3.1 Inventory management

Inventory management first appeared in the aviation industry. Pilots check lists to ensure safe flight, and in case of emergency accidents, emergency measures are implemented one by one according to the list. Inventory management has also been widely applied in healthcare, urban management, government power, trade access, enterprise management, construction engineering, food safety, and other areas. These fields have one thing in common - they all involve life safety, and a small negligence - a seemingly small bug or carelessness can cause extremely serious impacts. By adopting inventory management, errors caused by negligence can be effectively avoided - due to the involvement of multiple links, wide coverage, numerous factors, and complex formation mechanisms - it is difficult to overcome solely by improving the sense of responsibility of the parties involved and relying on their work experience accumulation.

3.2 Inventory management in escalator operations

In elevator management, the introduction of a list management approach clarifies the responsibilities of all parties in terms of management dimensions, clarifies the responsibilities and obligations of elevator users, maintenance parties, and regulatory parties. By developing detailed checklists and procedures, it is possible to ensure that all parties have a clear understanding of their responsibilities and obligations, thereby facilitating better collaboration and communication, and avoiding situations where responsibilities are unclear and buck passing occurs; In terms of quality, through standardized inspections, potential safety hazards can be identified and corrected. By regularly conducting detailed inspections and maintenance of elevators, potential problems can be identified in a timely manner and measures can be taken to solve them, thereby reducing the risk of elevator use, improving safety and reliability, and enhancing the overall safety of elevators; In terms of efficiency, through information disclosure, the safety information and maintenance records of elevators can be made public, allowing everyone to understand the usage and safety status of elevators, thereby better participating in management and supervision, and all staff participating in elevator safety management and risk governance, improving efficiency.

3.3 The process of checking the elevator inventory

The process of checking the elevator inventory, including sorting out key issues; Timely revision; Comprehensive summary and revision.One is to investigate key issues. In the process of checking the elevator inventory, the key issues need to be identified first. These key issues may include issues related to elevator safety, reliability, comfort, and energy efficiency. By sorting and analyzing these key issues, the focus of elevator maintenance and improvement can be determined.The second is to revise the list in a timely manner. The elevator inventory check needs to be conducted regularly to track the operation status of the elevator and promptly identify potential problems. At the same time, it is also necessary to revise the elevator list in a timely manner according to the actual situation, in order to reflect the latest status of elevators and meet actual needs. For example, when an elevator malfunctions, it is necessary to revise the list in a timely manner to reflect the cause and solution of the malfunction.The third is to comprehensively summarize and revise. In the process of checking the elevator inventory, it is necessary to conduct a comprehensive evaluation of the elevator. The evaluation may include issues related to the mechanical system, electrical system, safety protection system, and other aspects of the elevator. By evaluating these aspects, a comprehensive understanding of the condition and performance of elevators can be obtained, providing a basis for maintenance and improvement.

4 An example of a fast detection method for auxiliary brakes based on inventory management method

For elevators and escalators, the identification of their risk points is generally based on experience or case studies, compared to their main components. Xiaolun Wang and Xupeng Zhang conducted a failure analysis on the brake system of elevators using the AHP method, identified the main risk points of the braking system, and proposed governance measures[4].Zhang and Xupeng proposed a certification method for the safety of escalator functions in use[5].Zhang and Xupeng used a similar method to determine the risk points for using escalators[6].Xupeng Zhang Propose a large-scale escalator risk analysis method[7].Xupeng Zhang proposed a functional safety certification method for public transportation escalators based on the theory of functional safety and the practical application of electrical safety in public transportation escalators[8]. The methods mentioned in the above literature can be summarized as a technical approach from risk points to inspection items.

4.1 Classification of Auxiliary brake Faults Based on Fault Data

An analysis and statistics were conducted on 3110 faults in the Beijing subway. The faults related to the auxiliary brake of the escalator can be divided into faults in the auxiliary brake body, control unit, sensor unit, and actuator unit. Among them, the faults of the auxiliary brake body include deformation of the hook of the auxiliary brake, breakage of the connecting rod of the auxiliary brake, and damage to the switch of the auxiliary brake; Control unit failures include motherboard failures and damaged control cables; Sensor unit failures include sensor failures and elongated drive chains; The faults of the actuator unit include controller faults, brake coil faults, contactor jamming, and contactor damage.[9]

4.2 Weights of various factors for auxiliary brakes of escalators based on Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a hierarchical weight decision analysis method. Decompose complex problems into different hierarchical structures in the order of overall objectives, sub objectives at each level, and evaluation criteria, and divide these factors into ordered hierarchical structures according to their subordinate relationships. Using scaling theory and subjective and objective judgment, through pairwise comparison, determine the relative importance of each factor in the hierarchy and the total weight ranking of each element. After normalizing the feature vectors corresponding to each factor, it is the relative importance weight of a certain level indicator to a related indicator in the previous level.Using the AHP method to establish the weights of various factors related to the risk of auxiliary brakes, and establishing a risk assessment system, the process is divided into the following four steps. Using the data obtained from the previous method, identify risk points and determine the probability of occurrence and degree of harm;Use the Analytic Hierarchy Process to determine the matrix and determine the weight of each risk point;Evaluate each risk point and determine the risk level;Assess the results of the overall risk assessment and draw the conclusion of the safety assessment.

4.3 Calculation of criterion layer judgment matrix

According to the theory of Analytic Hierarchy Process, by comprehensively analyzing the four secondary indicators of ontology, control unit, sensing unit, and execution unit. Establish a criterion layer judgment matrix as shown in Table 1.

Figure 1 Criteria layer judgment matrix

A	B1	B2	B3	B4	Wi
B1	1.00	4.00	5.00	1.00	0.4132
B2	0.25	1.00	4.00	0.33	0.1640
B3	0.20	0.25	1.00	0.33	0.0785
B4	1.00	3.00	3.00	1.00	0.3444

Calculate the maximum eigenvalue=4.2412. Compatibility index C.I.=0.0804.Average consistency index RI=0.90.C.R.=0.0893<0.1 indicates that the judgment matrix meets the consistency requirements.

4.4 Calculation of Ontology Subcriteria Layer Judgment Matrix

According to the Analytic Hierarchy Process theory, a comprehensive analysis was conducted on the deformation of the hook of the auxiliary brake, the fracture of the connecting rod of the auxiliary brake, and the damage to the switch of the auxiliary brake. The judgment matrix of the sub criterion layer of the ontology was established as shown in Table 2.

Figure 2 Ontology Subcriteria Layer Judgment Matrix

A	B1	B2	B3	Wi
B1	1.00	1.00	1.00	0.3278
B2	1.00	1.00	2.00	0.4111
B3	1.00	0.50	1.00	0.2611

Calculate the maximum eigenvalue=3.0537.Compatibility index C.I.= 0.0268.Average consistency index RI=0.58.C.R.= 0.0463<0.1 indicates that the judgment matrix meets the consistency requirements.

4.5 Calculation of Control Unit Subcriteria Layer Judgment Matrix

According to the Analytic Hierarchy Process (AHP) theory, a comprehensive analysis is conducted on motherboard faults, control cable damage, and other factors to establish a sub criterion layer judgment matrix for control units, as shown in Table 3.

Figure 3 Control Unit Subcriteria Layer Judgment Matrix

A	B1	B2	B3	Wi
B1	1.00	1.00	9.00	0.4737
B2	1.00	1.00	9.00	0.4737
B3	0.11	0.11	1.00	0.0526

Calculate the maximum eigenvalue= 3.0000.Compatibility index C.I.= 0.Average consistency index RI=0.58.C.R.= 0<0.1 indicates that the judgment matrix meets the consistency requirements.

4.6 Calculation of Sensing Units Subcriteria Layer Judgment Matrix

According to the Analytic Hierarchy Process (AHP) theory, a comprehensive analysis was conducted on violations, including sensor faults, drive chain elongation, and other factors. A sub criterion layer judgment matrix for sensor units was established as shown in Table 4

Figure 4 Sensing Units Subcriteria Layer Judgment Matrix

A	B1	B2	B3	Wi
B1	1.00	2.00	9.00	0.6152
B2	0.50	1.00	5.00	0.3187
B3	0.11	0.20	1.00	0.0660

Calculate the maximum eigenvalue= 3.0012.Compatibility index C.I.= 0.0006.Average consistency index RI=0.58.C.R.= 0.0011 <0.1 indicates that the judgment matrix meets the consistency requirements.

4.7 Calculation of Execution Unit Subcriteria Layer Judgment Matrix

According to the Analytic Hierarchy Process (AHP) theory, a comprehensive analysis was conducted on illegal operations, including controller failures, brake coil failures, contactor jamming, and other factors. A judgment matrix for the sub criteria layer of the execution unit was established, as shown in Table 5.

Figure 5 Execution Unit Subcriteria Layer Judgment Matrix

A	B1	B2	B3	B4	Wi
B1	1.00	0.20	0.20	5.00	0.1139
B2	5.00	1.00	1.00	10.00	0.4252
B3	5.00	1.00	1.00	10.00	0.4252
B4	0.20	0.10	0.10	1.00	0.0358

Calculate the maximum eigenvalue= 4.1098.Compatibility index C.I.= 0.0366.Average consistency index RI=0.90.C.R.= 0.0407 <0.1 indicates that the judgment matrix meets the consistency requirements.

Based on the above results, the ranking and risk catalog of various influencing factors for the auxiliary brake are obtained, as shown in Table 6.

Figure 6 Ranking and Risk Catalogue of Various Influencing Factors for Auxiliary brakes

Criteria Layer	Subcriteria Layer Criteria Layer	Z- Wi	Wi	Composite Weights
Ontology	Auxiliary brake hook deformation	0.4132	0.3278	0.135447
	Auxiliary brake connecting rod broken		0.4111	0.1699
	Auxiliary brake switch damaged		0.2611	0.1079
Control unit	Main board malfunction	0.164	0.4737	0.0777
	Control cable damage		0.4737	0.0777
	Other faults in the control unit		0.0526	0.0086
Sensing unit	Sensor malfunction	0.0785	0.6152	0.0483
	Drive chain elongation		0.3187	0.0250
	Other faults in the sensing unit		0.066	0.00521
Execution unit	Controller malfunction	0.3444	0.1139	0.0392
	Brake coil malfunction		0.4252	0.1464
	Contactor jamming		0.4252	0.1464
	Other faults in the execution unit		0.0358	0.0123

It can be seen that the most important items are the breakage of the connecting rod of the auxiliary brake, brake coil failure, contactor jamming, etc[10]. The integrity inspection, electrical contact and switch inspection of the mechanism are the key points of the inspection of the auxiliary brake of the escalator. Finally, the inspection list of the auxiliary brake of the escalator is obtained, as shown in Table 7.

Figure 7 Checklist for auxiliary brakes on escalators.

Secondary indicators	Tertiary indicators and their content
Visual inspection	Check if the auxiliary brake guide shoe is deformed
	Check if the electromagnetic coil, brake lever, and guide device are intact
	Is the brake shoe worn
	Check for debris in the surrounding environment
	Check for abnormal noise during operation
Electrical	Is the triggering mechanism working properly

inspection	Is the safety switch operating normally
Adjustment	Host end torque adjustment
	Adjusting the clearance of the push rod
Cleaning and lubrication	Cleaning various components
	Add lubricating oil according to regulations
Functional inspection	Static load rolling test
	Dynamic load (full load) test
	Simulate actions

5 Conclusion

This article analyzes the structural characteristics of the additional brake for escalators, and conducts statistical analysis on the fault data to identify the risk points of the additional brake for escalators.

The weights of each risk factor were obtained through the Analytic Hierarchy Process, and a risk algorithm model for the additional brake of an escalator was established.

Based on the concept of simple, reliable, and effective inventory management, a rapid detection method for additional brakes on escalators based on inventory management has been established.

This method can effectively inspect the additional brakes of escalators and can also be applied to the quality inspection of the working brakes of elevators and escalators, which has reference significance for the inspection of other complex equipment.

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