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Research Article

Rapid Fault Diagnosis Method of Elevator System Based on Multiattribute Decision Making

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Fault tree analysis is often used in elevator fault diagnosis because of its simplicity and reliability. However, the traditional fault tree method has the problems of low efficiency due to ignoring location change of bottom events during troubleshooting. This paper proposes a rapid diagnosis method based on multiattribute decision making to solve the problem. The fault tree of the elevator system is constructed based on expert knowledge and multisource data, and the location-related matrix is constructed according to the complex vertical structure of the elevator. Then, the attributes of bottom events such as the failure probability, search cost, location time cost, and location-related attributes are comprehensively analyzed in this paper. Finally, the TOPSIS method for dynamic attributes is used based on the work above to achieve the optimal troubleshooting sequence of elevator vibration fault. The results show that the proposed method is more efficient when compared to the optimal troubleshooting sequence obtained by the traditional method.

1. Introduction

With the rapid development of urban construction, the usage of elevators is increasing. Elevator failures are gradually increasing, and the time between failures is significantly decreasing. Once the elevator fails, it brings huge losses. The longer the time spent on troubleshooting, the greater the economic loss and the damage to passengers. Statistics show that the time used to find faults in complex electromechanical systems accounts for more than 60% of the entire repair time, and the time spent to directly troubleshoot takes less than 40%. Therefore, improving the diagnostic efficiency of the elevator can significantly reduce the economic loss and the injury to passengers. Furthermore, it is of great significance to develop and study the reasonable order of fault inquiry for elevator fault diagnosis.

The fault tree analysis method is widely used in fault diagnosis due to its simple and reliable characteristics [1–4]. The current applications of fault tree analysis methods for troubleshooting mainly include the following. Yang et al. [5, 6] studied the “dimension explosion” problem in fault tree analysis and applied the binary decision diagram algorithm to fault tree analysis to solve the problem, but there was not too much research on making a reasonable fault diagnosis sequence. Gao et al. [7] developed a fault diagnosis system for electric vehicle charging equipment based on FTA design to achieve rapid troubleshooting, but the research lacks consideration of search costs and location and other attributes. Xia et al. [8] applied a new method based on fuzzy set theory to fault tree analysis to quantify the failure probability of basic events, which overcomes the difficulty of obtaining failure probability to a certain extent, but the factors involved in troubleshooting are more one-sided. He et al. [9] combined the fault tree analysis and TOPSIS methods to comprehensively analyze the structural importance, probability importance, and critical importance of the minimum cut set but ignored the maintenance cost. Zhang et al. [10] combined the fault tree analysis with the risk matrix method to comprehensively consider the frequency of failures and the cost of loss, which has a higher degree of discrimination and accuracy than a single fault tree, but did not consider the impact of the location of the fault on the cost. Chen et al. [11] proposed a fuzzy Bayesian network inference fault diagnosis model for complex equipment based on fault trees, which not only solves the problem that the use of search functions in Bayesian networks to construct the optimal network is not in line with reality but also solves the lack of complex equipment data, and inadequate expert scores are not accurate enough. Zong et al. [12, 13] analyzed the importance of the minimum cut set of the fault tree, generated the test process according to the principle of first detection of the minimum cut set with high importance, and combined it with the expert system to achieve rapid fault diagnosis. However, the research lacked the search cost and consideration of attributes such as location. Abu-Hanna and Gold [14] optimized the fault search strategy based on fault tree analysis and gave a qualitative description of the detection cost in fault diagnosis but did not consider the failure probability and location factors. Yao et al. [15–17] proposed fault tree analysis and fault troubleshooting methods and made fault search decisions by comprehensively considering fault probability and search cost of fault components, without considering the influence of location factors on search cost. In view of the problems existing in fault tree analysis, the above research integrates Petri net, BDD, fuzzy theory, TOPSIS, expert system, and other related methods to provide ideas for fault diagnosis of the elevator system, but there are still some shortcomings.

This paper presents a rapid diagnostic method for the elevator system. This method further considers the location factor of elevator components on the basis of predecessors and shows the influence of location on troubleshooting by constructing location time cost attributes and location-related matrix. Moreover, this method solves the problem that the TOPSIS method cannot be applied to dynamic location-related attributes by conditionally reusing the TOPSIS method.

The structure of this article is as follows. Section 2 establishes the elevator vibration fault tree and analyzes the blindness of the traditional fault tree analysis. Section 3 briefly introduces the TOPSIS method, which cannot be applied to dynamic location association attributes without modification. Section 4 constructs the location incidence matrix and a new TOPSIS method for dynamic attributes. In Section 5, the method is applied to the elevator vibration fault tree to get the optimal troubleshooting sequence, and the sequence is compared with the traditional troubleshooting sequence to verify the effectiveness of the method proposed in this paper.

2. Elevator Fault Location Based on Fault Tree Analysis

2.1. Construction of Elevator Vibration Fault Tree. Elevator failure phenomena are mainly divided into elevator vibration failure, car noise failure, machine room noise failure, gate opening and closing failure, etc. The occurrence of failures has different impacts on the operation of the elevator, of which elevator vibration failure affects the smooth operation of the elevator largely, and the cause of the fault phenomenon is most widely distributed in the elevator system. Next, the elevator vibration fault is taken as an example to construct a fault tree and implement the subsequent algorithm.

For permanent magnet synchronous traction elevators in cold regions, considering the influence of low temperature and snow weather, a fault tree of elevator vibration fault is constructed based on expert knowledge and multisource data.

The fault tree of elevator car vibration failure is shown in Figure 1 and Table 1. It has 15 bottom events, including many important equipment of the elevator. The bottom events are x_1 (deviation occurs during installation of guide rails and guide shoes), x_2 (the guide rails and guide shoes are severely worn), x_3 (the lubricating oil of guide rails solidifies), x_4 (the guide rails are frozen), x_5 (deviation occurs during installation at the joint of guide rails), x_6 (the bolts of guide rail brackets are loose), x_7 (the fastening bolts of the reverse sheave frame are loose), x_8 (the bearings of the reverse sheave are worn), x_9 (the anchor bolts of the traction machine are loose), x_{10} (the base of the traction machine is not flat), x_{11} (overheating of the electric motor causes its lubricating oil to dilute), x_{12} (the lubricating oil of motor bearings solidifies), x_{13} (the tension of the wire rope is uneven), x_{14} (too much lubricating oil in the traction wheel groove causes slippage), and x_{15} (uneven grease lumps in the traction wheel groove).

The bottom event of the fault tree represents the possible fault cause or fault element, and the cut set represents the set of basic events that lead to the occurrence of top events. The minimum cut set is the minimum cut set that causes the occurrence of top events [18–21]. The main purpose of fault tree analysis is to find all the minimum cut sets of the fault tree. As shown in Figure 1, all events in the elevator vibration fault tree are connected by OR gates, so the minimum cut set is each base event of the fault tree, which can also be understood as each base event will cause the occurrence of top events.

2.2. Locating Fault. The elevator is a special equipment with complex vertical structure, including machine room part, hoistway and pit part, car part, and landing part, and its structure is shown in Figure 2. From the vibration fault tree of the elevator, we can know that there are many reasons for the vibration fault. When the vibration fault occurs, the existing technology cannot accurately locate which part of the elevator has a fault, so it is necessary to find the real cause of the fault through troubleshooting. When professionals troubleshoot faults, they often need to perform cumbersome steps in the early stage. These steps include debugging the control cabinet in the machine room, entering the car top, and entering the pit, which usually incurs a lot of costs. How to work out a reasonable and efficient troubleshooting sequence while ensuring a lower cost is the focus of this paper.

According to the theory of the fault tree analysis method, if the failure probability of each bottom event is equal, the troubleshooting order is sequential search until the fault location and cause are found; if the failure probability is different, the search is performed according to the failure

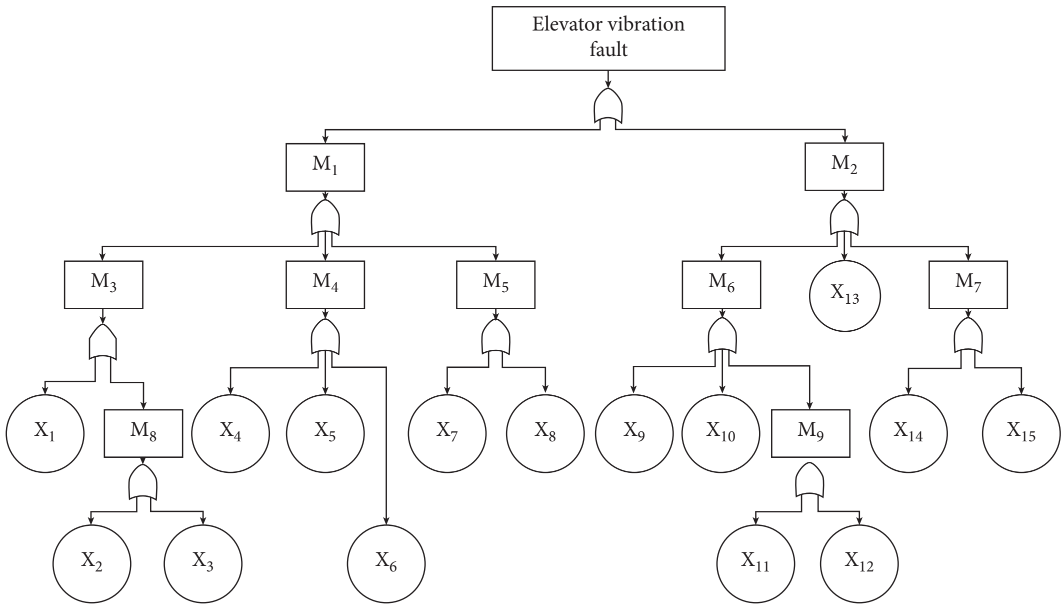

Figure 1: The elevator vibration fault tree.

Table 1: Event coding.

ID	Event name
M_1	Horizontal vibration fault
M_2	Vertical vibration fault
M_3	Improper clearance between guide shoes and guide rails
M_4	The guide rails are not flat
M_5	Reverse sheave vibration failure
M_6	Traction machine vibration failure
M_7	Traction wheel lubricating oil fault
M_8	The guide shoe bushers are severely worn
M_9	The bearings of traction motor are severely worn
x_1	Deviation occurs during installation of guide rails and guide shoes
x_2	The guide rails and guide shoes are severely worn
x_3	The lubricating oil of guide rails solidifies
x_4	The guide rails are frozen
x_5	Deviation occurs during installation at the joint of guide rails
x_6	The bolts of guide rail brackets are loose
x_7	The fastening bolts of the reverse sheave frame are loose
x_8	The bearings of the reverse sheave are worn
x_9	The anchor bolts of the traction machine are loose
x_{10}	The base of the traction machine is not flat
x_{11}	Overheating of traction motor causes its lubricating oil to dilute
x_{12}	The lubricating oil of traction motor bearings solidifies
x_{13}	The tension of the wire rope is uneven
x_{14}	Too much lubricating oil in the traction wheel groove causes slippage
x_{15}	Uneven grease lumps in the traction wheel groove

probability [17, 18]. This method is very blind because in the actual operation, the technical personnel, the tools and the equipment used, the difficulty of detection, and the funds invested in each incident investigation process are different, which causes the search cost of each incident to be different. If the change of search cost is not considered, the efficiency of troubleshooting will be very low.

The blindness of the traditional fault tree search method is also reflected in ignoring the influence of location factor. Firstly, the location of the bottom event affects costs. The search cost is usually defined as the time required to detect a suspected faulty component and the corresponding disassembly workload, while the cost of reaching the location of the bottom event is rarely calculated. Since elevator is a vertical complex electromechanical device, the cost of reaching the location of the fault component is higher than that of ordinary electromechanical devices, so the location of the bottom event should be considered as a factor to specify

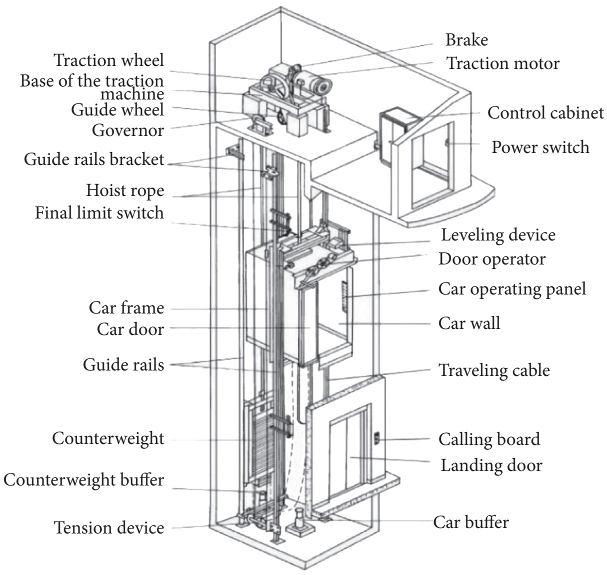

Figure 2: The structure of the elevator.

the troubleshooting sequence. Secondly, the relationship between the locations of each base event will also bring about the change of cost. Taking elevator vibration failure as an example, in the traditional fault tree investigation, when facing the situation of turning back to the machine room and car roof multiple times, the search cost is undoubtedly greatly increased. There also exists a situation of checking different positions of the same component and the cost must be reduced. The definition of search cost in the existing fault detection research is invariable, and the cost change caused by the change of location is often ignored. Therefore, location-related attributes should be taken into consideration.

To sum up, the problem of the optimal troubleshooting sequence of each bottom event can be solved only by comprehensively considering the search cost, failure probability, location time cost, dynamic relationship, and other attributes of each bottom event and constructing the multiattribute decision theory for dynamic attributes.

3. TOPSIS

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is widely used in multiattribute decision making [22–25]. Its main idea is to construct the positive ideal solution (PIS) and negative ideal solution (NIS) of the evaluated object and then calculate the distance to PIS and NIS to complete the ranking problem. The PIS is the virtual best scheme where every attribute value is optimal. On the contrary, the NIS is the virtual worst scheme where each attribute value is the worst. The distance between each scheme and the positive and negative ideal solutions can be compared to determine the priority of these schemes. The best scheme is near the PIS and away from NIS, and the worst scheme is inverse. The TOPSIS method can be performed as follows.

First, let $x = \{x_1, x_2, \cdots, x_n\}$ be the set of alternatives for the multiattribute decision-making problem, and $y_i = \{y_{i1}, y_{i2}, \cdots, y_{im}\}$ represents the set of attribute values of the scheme x_i. The attribute value of each search scheme can be represented by the search decision matrix Y, $Y = \{y_{ij}\}$.

Due to the different physical dimensions of different performance indicators, the data corresponding to each attribute need to be standardized. After processing, get the normalized matrix Z, and the normalized decision matrix can be obtained by the following equation:

$$z_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{n} {y_{ij}}^2}}. \tag{1}$$

Considering the weight vector of the attributes $[w_1, w_2, \ldots\ldots, w_m]^T$, the weighted normalized decision matrix $X = \{X_{ij}\}$ can be obtained by the following equation:

$$X_{ij} = w_j \cdot z_{ij}. \tag{2}$$

We suppose that X^+ refers to the PIS and X^- refers to the NIS. They are presented as follows:

$$\left.\begin{aligned} X^+ &= \left\{\left(\max_i X_{ij} | j \in J\right), \left(\min_i X_{ij} | j \in J'\right)\right\} = \{X_1^+, X_2^+, \ldots, X_m^+\} \\ X^- &= \left\{\left(\min_i X_{ij} | j \in J\right), \left(\max_i X_{ij} | j \in J'\right)\right\} = \{X_1^-, X_2^-, \ldots, X_m^-\} \end{aligned}\right\}, \tag{3}$$

where J and J' are benefit-type and cost-type attribute sets, respectively.

Calculate the distance from each scheme to the PIS and NIS:

$$\begin{aligned} d_i^+ &= \sqrt{\sum_{j=1}^{m} \left(X_{ij} - X_j^+\right)^2}, \\ d_i^- &= \sqrt{\sum_{j=1}^{m} \left(X_{ij} - X_j^-\right)^2}. \end{aligned} \tag{4}$$

Define the relative closeness C_i^+ from the solution to the ideal solution as

$$C_i^+ = \frac{d_i^-}{d_i^+ + d_i^-} 0 \leq C_i^+ \leq 1. \tag{5}$$

If the value of C_i^+ is large, the corresponding plan should be ranked first. Therefore, according to the order of C_i^+ from largest to smallest, the first plan should be checked first.

4. The TOPSIS Method for Dynamic Attributes

When troubleshooting in a given order, the cost of each event will change as the location changes, and the cost score needs to be re-estimated by experts. However, it is obviously unreasonable to ask an expert to score every time the location is changed. For this reason, it is necessary to introduce the attributes related to the location factor—location time cost and location-related attribute, which represent the cost brought by location and the relative relationship between locations. When these two attributes are introduced, the cost score estimation can be flexibly applied to various occasions of troubleshooting location transformation.

Therefore, it is necessary to comprehensively consider the four attributes of failure probability, search cost, location time cost, and location-related attributes in troubleshooting. Among them, the first three attributes will not change after being scored by experts, and the last attribute will change as troubleshooting progresses. At this time, the TOPSIS method needs some optimization before it can be used in troubleshooting.

4.1. Location-Related Matrix. The location-related attribute describes the location relationship between the bottom events. The location-related scores of the bottom events can be given by the expert according to the distance of the location according to the 1–9 scale method. The location-related scores of the same bottom event are 1. The location-related scores of the different bottom events are scored as 1/9, 1/7, 1/5, or 1/3 according to whether the distance between their location is extremely close, very close, close, or slightly close. In the same way, score 3, 5, 7, or 9 according to whether the distance between different event locations is slightly far, far, very far, or extremely far.

The location-related scores of the bottom events can form a location-related matrix, which is convenient for us to extract the location-related scores according to different screening order, thus eliminating the step of frequently scoring the cost. The form of location-related matrix B is as follows:

$$B = \begin{matrix} & x_1 & x_2 & \cdots & x_n \\ x_1 & 1 & b_{12} & \cdots & b_{1n} \\ x_2 & b_{21} & 1 & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_n & b_{n1} & b_{n2} & \cdots & 1 \end{matrix}. \quad (6)$$

4.2. The TOPSIS Method for Dynamic Attributes. In the troubleshooting process, location-related scores are not static. When professionals rush from equipment A to equipment B according to the troubleshooting sequence, the location-related attributes of the remaining troubleshooting items in the troubleshooting sequence will change from being related to equipment A to being related to equipment B, and the location-related score will change accordingly. The traditional TOPSIS method is only suitable for static multiattribute decision making and cannot be applied to the troubleshooting of elevator vibration faults. In the face of dynamically changing location-related attributes, we have improved the TOPSIS method.

Let $x = \{x_1, x_2, \cdots, x_n\}$ be the set of alternatives for the multiattribute decision-making problem, and its location-related matrix is $B = \{b_{ij}\}$, where b_{ij} is the location-related score of the bottom event x_i to the bottom event x_j $(i, j = 1, 2, \ldots, n)$. $y_i = \{y_{i1}, y_{i2}, \cdots, y_{im}\}$ is the set of static attribute values of the bottom event x_i, where y_{ij} is the jth $(j = 1, 2, \ldots, m)$ static attribute of the ith $(i = 1, 2, \ldots, n)$ bottom event. The static search decision matrix is represented by $Y = \{y_{ij}\}$.

Use the TOPSIS method for static attributes to obtain the troubleshooting sequence that does not consider the location-related attributes. Set the first bottom event in the troubleshooting sequence as x_i, and the sequence of $(n-1)$ th bottom events after extracting x_i is T. Find the column matrix $[b_{1i}, b_{2i}, \ldots, b_{ni}]^T$ corresponding to the x_i column in the location-related matrix B and find the location-related scores in the column matrix according to T.

Use the TOPSIS method for the mth static attributes and position-related attributes of the remaining $(n-1)$th bottom events to obtain a new sequence $T\prime$. Repeat the above steps and end the loop when there are only two bottom events left. Sort the bottom events according to the order of extraction and add the last two bottom events in the existing order at the end to get the optimal troubleshooting sequence of troubleshooting. The detailed process is shown in Figure 3.

5. Troubleshooting for Elevator Vibration Failure

We take the vibration fault of elevator as an example and apply the above method to verify its feasibility. As shown in Section 2, there are 15 bottom events of elevator vibration failure. As shown in equation (6), the location-related scores of bottom events are given according to the relative position between the bottom events, which can form the location-related matrix B with 15 rows and 15 columns. The location-related matrix is displayed in the form of a table, as shown in Table 2.

Based on the multi-source data provided by manufacturers and the empirical knowledge of domain experts, this paper determines the values of three attributes of failure probability, search cost, and location time cost of each bottom event. The value range of failure probability is 0~1, and the value range of search cost and location time cost is 0~10. The scoring is shown in Table 3, and the distribution of each attribute score is shown in Figure 4.

The TOPSIS method is used for the scores of the above static attributes, and the ranking results are shown in Table 4 and Figure 5.

The third step is to extract the first bottom event x_{15} in the above order to obtain the order $T = [x_3, x_{12}, x_2, x_9, x_7, x_6, x_{14}, x_{13}, x_{11}, x_8, x_4, x_{10}, x_5, x_1]^T$, extract the scores from the location-related matrix in this order, and put them into the decision matrix as a new attribute, as shown in Table 5.

The fourth step is to sort the above scores by the TOPSIS method to get the order, considering the relative relation between bottom event x_{15} and the remaining bottom events: $T\prime = [x_3, x_{12}, x_9, x_2, x_7, x_{14}, x_6, x_{13}, x_{11}, x_8, x_{10}, x_4, x_5, x_1]^T$.

Repeat the third and fourth steps until two bottom events are left. Sort the bottom events in the order of extraction, and the optimal troubleshooting sequence for the bottom events of the elevator vibration fault tree is $x_{15}, x_3, x_{12}, x_9, x_2, x_6, x_7, x_{13}, x_{14}, x_{11}, x_8, x_4, x_5, x_{10}, x_1$.

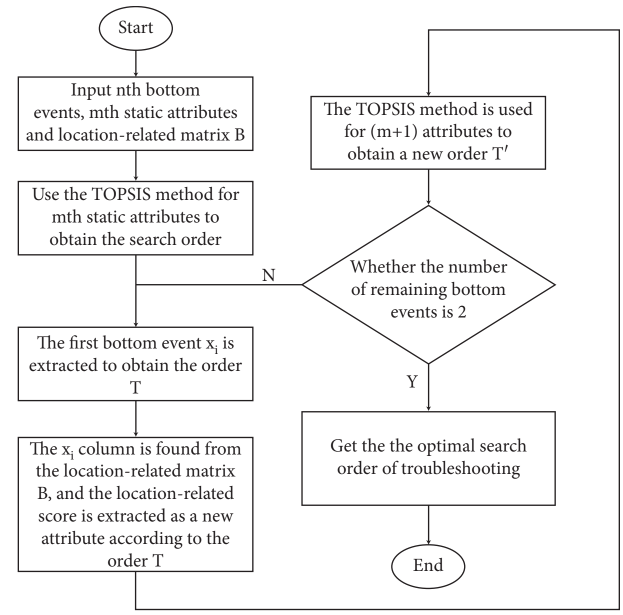

Figure 3: The flowchart of TOPSIS method for dynamic attributes.

Table 2: The location-related matrix B.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
x_1	1	1/7	1/7	1/7	1/7	1/7	1/3	1/3	5	5	5	5	1/5	5	5
x_2	1/7	1	1/7	1/7	1/7	1/7	1/3	1/3	5	5	5	5	1/5	5	5
x_3	1/7	1/7	1	1/7	1/7	1/7	1/3	1/3	5	5	5	5	1/5	5	5
x_4	1/7	1/7	1/7	1	1/7	1/7	1/3	1/3	5	5	5	5	1/5	5	5
x_5	1/7	1/7	1/7	1/7	1	1/7	1/3	1/3	5	5	5	5	1/5	5	5
x_6	1/7	1/7	1/7	1/7	1/7	1	1/3	1/3	5	5	5	5	1/5	5	5
x_7	1/3	1/3	1/3	1/3	1/3	1/3	1	1/7	7	7	7	7	1/5	7	7
x_8	1/3	1/3	1/3	1/3	1/3	1/3	1/7	1	7	7	7	7	1/5	7	7
x_9	5	5	5	5	5	5	7	7	1	1/7	1/5	1/5	3	1/5	1/5
x_{10}	5	5	5	5	5	5	7	7	1/7	1	1/5	1/5	3	1/5	1/5
x_{11}	5	5	5	5	5	5	7	7	1/5	1/5	1	1/7	3	1/5	1/5
x_{12}	5	5	5	5	5	5	7	7	1/5	1/5	1/7	1	3	1/5	1/5
x_{13}	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	3	3	3	3	1	3	3
x_{14}	5	5	5	5	5	5	7	7	1/5	1/5	1/5	1/5	3	1	1/7
x_{15}	5	5	5	5	5	5	7	7	1/5	1/5	1/5	1/5	3	1/7	1

Table 3: The score of the static attributes.

ID	Bottom event	Failure probability (%)	Search cost	Location time cost
x_1	Deviation occurs during installation of guide rails and guide shoes	0.2	3.62	5
x_2	The guide rails and guide shoes are severely worn	1.6	3.62	5
x_3	The lubricating oil of guide rails solidifies	2.6	3.62	5
x_4	The guide rails are frozen	0.8	3.62	5
x_5	Deviation occurs during installation at the joint of guide rail	0.3	3.62	5
x_6	The bolts of guide rail brackets are loose	1.4	3.62	5
x_7	The fastening bolts of the reverse sheave frame are loose	1.6	4.8	4
x_8	The bearings of the reverse sheave are worn	1.3	8.08	7
x_9	The anchor bolts of the traction machine are loose	1.4	1	2
x_{10}	The base of the traction machine is not flat	0.2	1	2
x_{11}	Overheating of the electric motor causes its lubricating oil to dilute	1.3	6.52	2
x_{12}	The lubricating oil of motor bearings solidifies	2.3	6.52	2
x_{13}	The tension of the wire rope is uneven	1.4	4.24	4
x_{14}	Too much lubricating oil in the traction wheel groove causes slippage	1.3	2.84	2
x_{15}	Uneven grease lumps in the traction wheel groove	2.6	2.84	2

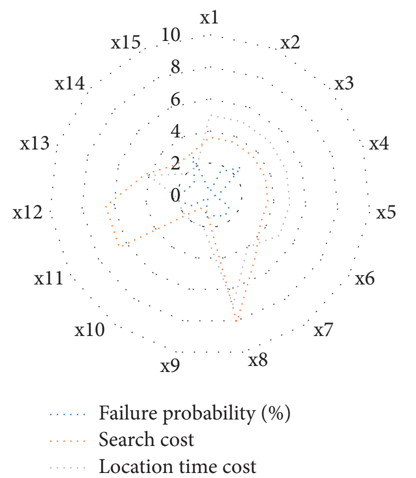

Figure 4: The score of the static attributes.

Table 4: The ranking results of the static attributes.

ID	Bottom event	The ranking result
x_{15}	Uneven grease lumps in the traction wheel groove	0.90110553
x_3	The lubricating oil of guide rails solidifies	0.85725351
x_{12}	The lubricating oil of motor bearings solidifies	0.70530025
x_2	The guide rails and guide shoes are severely worn	0.58969769
x_9	The anchor bolts of the traction machine are loose	0.57472079
x_7	The fastening bolts of the reverse sheave frame are loose	0.56311343
x_6	The bolts of guide rails brackets are loose	0.52062572
x_{14}	Too much lubricating oil in the traction wheel groove causes slippage	0.50779374
x_{13}	The tension of the wire ropes is uneven	0.50760147
x_{11}	Overheating of the electric motor causes its lubricating oil to dilute	0.42542178
x_8	The bearings of the reverse sheave are worn	0.39327756
x_4	The guide rails are frozen	0.32921399
x_{10}	The base of the traction machine is not flat	0.31247737
x_5	Deviation occurs during installation at the joint of guide rails	0.22717022
x_1	Deviation occurs during installation of guide rails and guide shoes	0.21817456

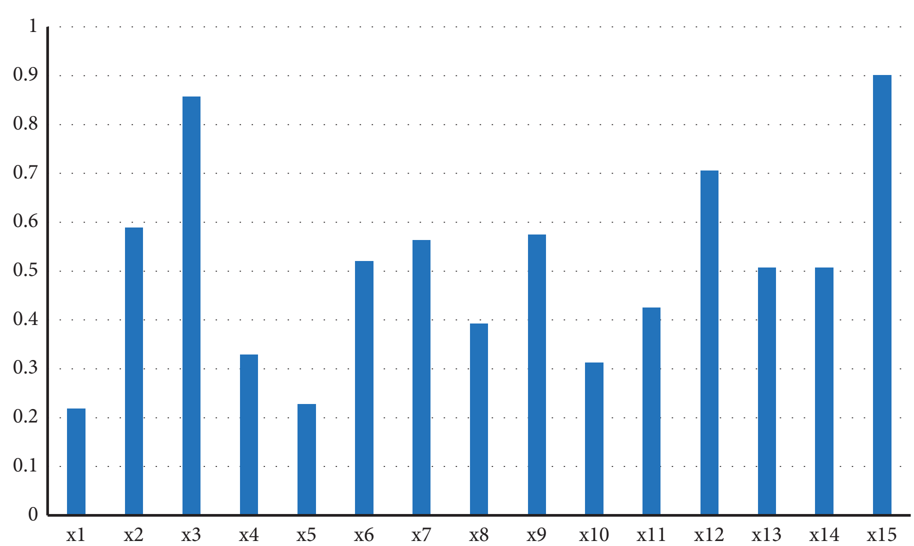

Figure 5: The ranking results of the static attributes.

Table 5: Scores of four attributes.

ID	Bottom event	Failure probability (%)	Search cost	Location time cost	Location-related score
x_3	The lubricating oil of guide rails solidifies	2.6	3.62	5	5
x_{12}	The lubricating oil of motor bearings solidifies	2.3	6.52	2	0.2
x_2	The guide rails and guide shoes are severely worn	1.4	1	2	0.2
x_9	The anchor bolts of the traction machine are loose	1.6	3.62	5	5
x_7	The fastening bolts of the reverse sheave frame are loose	1.6	4.8	4	7
x_6	The bolts of guide rails brackets are loose	1.3	2.84	2	0.1428
x_{14}	Too much lubricating oil in the traction wheel groove causes slippage	1.4	3.62	5	5
x_{13}	The tension of the wire rope is uneven	1.4	4.24	4	3
x_{11}	Overheating of the electric motor causes its lubricating oil to dilute	1.3	6.52	2	0.2
x_8	The bearings of the reverse sheave are worn	1.3	8.08	7	7
x_4	The guide rails are frozen	0.2	1	2	0.2
x_{10}	The base of the traction machine is not flat	0.8	3.62	5	5
x_5	Deviation occurs during installation at the joint of guide rails	0.3	3.62	5	5
x_1	Deviation occurs during installation of guide rails and guide shoes	0.2	3.62	5	5

Table 6: Evaluation matrix.

Index	Weight	The traditional troubleshooting sequence	The optimal troubleshooting sequence
Cost	0.33	0.17	0.83
Efficiency	0.67	0.25	0.75

Traditional fault tree analysis is to sort according to the probability of failure. By performing traditional fault tree analysis on elevator vibration faults, the troubleshooting sequence can be obtained as $x_3, x_{15}, x_{12}, x_2, x_7, x_9, x_6, x_{13}, x_{14}, x_{11}, x_8, x_4, x_5, x_{10}, x_1$.

For complex electromechanical equipment systems, there are many troubleshooting options available, and people hope to find out the fault cause as soon as possible at the lowest cost. Therefore, the analytic hierarchy process is used to evaluate the above two search sequences from two aspects of cost and efficiency, and the evaluation matrix is obtained, as shown in Table 6.

The comprehensive score of traditional troubleshooting sequence is 0.18, while that of troubleshooting sequence is 0.71. From the score, we can clearly see that the optimal troubleshooting sequence is better than the traditional troubleshooting sequence in terms of cost and efficiency.

The method proposed in this paper comprehensively considers attributes such as failure probability, search cost, location time cost, and location correlation. Compared with the traditional fault tree analysis, the troubleshooting sequence obtained by this method is more objective and reasonable, and the process of fault diagnosis and location is more rapid and effective.

6. Conclusion

In this paper, an elevator fault tree is established based on expert knowledge and multisource data, and a TOPSIS method for dynamic attributes is constructed by comprehensively considering fault probability, search cost, location time cost, and location-related of bottom events. By using AHP to evaluate the traditional troubleshooting sequence and the optimal troubleshooting sequence, the optimal troubleshooting sequence has higher efficiency and lower cost in troubleshooting. The method proposed in this paper can objectively determine the fault troubleshooting sequence and improve the efficiency of fault diagnosis.

Data Availability

The expert scoring data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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