Research Article

Research on the Selection of Factors in a Traction Fault Elevator Based on PCA and a Rough Set

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To the problem of large subjectivity in existing index screening methods, this paper uses principal component analysis and the rough set method to select faulty factors in a traction fault elevator, eliminate the unrelated and unimportant indices, and then set up 4 main indices: rated parameter, running environment, manufacturing maintenance condition, and man-machine factor; and 10 two-grade fingers, including rated load, use unit, and manufacturing unit, which constitute a traction failure elevator factor index system, provide a new train of thought and method for the research and analysis of traction fault elevators.

1. Introduction

In recent years, with the rapid increasing of elevator’s quantity, incidents of trapped and hurting people in elevators have frequently occurred, and elevator safety issues have also received increasing attention. From the perspective of an elevator which has failed, it is particularly important to filter the failure elevator factor indicators for studying elevator safety.

Domestic and foreign researchers have selected elevator safety indicators mainly from the internal factors of the elevator, and most of the methods used are the analytic hierarchy process (AHP) or fuzzy comprehensive evaluation methods and other subjective methods. Qing et al. [1] used the interval estimation analysis theory of the fuzzy comprehensive evaluation method to screen the indicators and used the AHP to obtain the corresponding weights of each indicator, finally analysing and evaluating the safety level of the elevator. Zheng [2] proceeded from the internal operating parameters of the elevator, using the AHP to determine the index weight, and the fuzzy comprehensive evaluation method was used to calculate the safety value of the elevator. A two-level evaluation method combining analytic hierarchy process and fuzzy comprehensive evaluation method is proposed by Zhu et al. [3], which created a practical theoretical model and evaluation criteria to evaluate the usefulness of object.

At the same time, the data collection of faulty elevators is difficult. In the current elevator evaluation system, the accurate evaluation of elevator risk is often unable to be realized because of insufficient data. Rough set does not need multiple groups of evaluation data and can carry out effective analysis and processing from a small amount of evaluation data [4] so as to determine the simplicity and importance of indicators, which has a good practical value for elevator risk evaluation. Wei et al. has obtained the weight of each attribute by the method of conditional entropy in rough set theory [5]. Qian used the rough set theory to research the credit risk assessment of commercial banks, and realized the accurate evaluation of the credit risk [6]. These objective methods based on the rough set theory completely rely on historical data to determine attribute weight. Although they avoid the influence of subjective factors, they pay too much attention to objective data and ignore the influence of condition changes.

In order to solve the problem of determining the index of elevator safety evaluation system, this paper starts from the perspective of faulty elevator to screen the failure index.
factors using principal component analysis (PCA) and rough sets. Based on the attribute importance in rough set theory and analytic hierarchy process, the combination weight of each attribute is determined [7, 8], it can effectively transform incomplete information systems into complete information systems without the influence of subjective factors of experts, and establish a scientific index system [9]. The combination of the rough set method and PCA in a statistical method makes the construction of the index system more scientific and has more research significance.

2. The Basis of Traction-Type Failure Elevator Factor Index Screening

2.1. The Basic Principle

2.1.1. Basic Principles of Index Selection. To make the screening indicators more scientific, it is necessary to combine qualitative analysis and quantitative analysis when screening indicators. In qualitative analysis, to make the constructed index system more scientific, six principles should be followed in the index selection process, namely, objective, complete, workable, independent, significant, and dynamic, referred to as “OCWISD” principles.

In quantitative analysis, it is easy to find relevant variables for linear problems and some specific nonlinear problems by using traditional methods [10]. The principle is to use statistical methods to filter and reduce a large number of original indicators to become grouping indicators with significant statistical characteristics. This method is difficult to screen when faced with complex nonlinear problems. This paper mainly uses PCA to reduce a large number of indicators into grouped indicators with significant statistical characteristics, filters out the traction-type fault elevator factor indicators, and uses the rough set method based on the rough set attribute reduction principle to analyse the redundant correlation indicators of the equivalent relationship. Once irrelevant and unimportant indicators are eliminated or successfully screened, one can finally obtain the traction-type failure elevator factor indicators and ensure that the result analysis was not affected.

2.1.2. Principles of Index System Construction. There is no fixed model for the construction of the index system. Different researchers and different starting angles can lead to different index systems. However, the following important principles must be followed during the construction of the index system: the content of the research; the construction of the index system must be contextual, and the corresponding index system must be constructed according to the specific situation, and specific issues must be analyzed in detail; the construction of the index system must be dynamic, and the research objects must be corresponding to the changes in the attention of researchers in different periods of changes and adjustments.

2.2. Principal Component Analysis. PCA is the method which replaces most of the original variables with a small number of main variables, and transforms them into the unrelated variables. Usually, a small number of variables are selected to replace most of the original variables, which is the principal components, that is, on the premise of retaining the original index information, a few unrelated principal components are used to replace the original index as much as possible, and so the dimension reduction could be realized [11].

For the study of traction fault elevator factors, it is assumed that x indicators are used to reflect the indicator data of q different regions, and the values of x indicators in each region are \( m_1, m_2, m_3, \ldots, m_x \). The new indicator is indicated by \( n_1, n_2, n_3, \ldots, n_x \). Then, the x indicators of \( m = (m_1, m_2, m_3, \ldots, m_x) \) can be integrated into \( y \) new indicators, and the new indicators can be expressed linearly with the original indicators \( m_1, m_2, m_3, \ldots, m_x \), namely:

\[
\begin{align*}
0 &= \mu_{11}m_1 + \mu_{12}m_2 + \cdots + \mu_{1x}m_x \\
0 &= \mu_{21}m_1 + \mu_{22}m_2 + \cdots + \mu_{2x}m_x \\
&\vdots \\
0 &= \mu_{y1}m_1 + \mu_{y2}m_2 + \cdots + \mu_{yx}m_x.
\end{align*}
\]

(1)

In formula (1), the coefficient \( \mu_{ij} \) is the principal component load \( i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \), which is the eigenvector of \( x \) eigenvalues of the correlation matrix \( m_1, m_2, m_3, \ldots, m_x \).

The corresponding matrix \( Q \) is established to find the eigenvalues and eigenvectors of the correlation matrix:

\[
Q = \begin{pmatrix}
q_{11} & q_{12} & \cdots & q_{1x} \\
q_{21} & q_{22} & \cdots & q_{2x} \\
\vdots & \vdots & \ddots & \vdots \\
q_{x1} & q_{x2} & \cdots & q_{xx}
\end{pmatrix}
\]

(2)

In formula (2), \( q_{ij} (i = 1, 2, 3, \ldots, x) \) is the correlation coefficient of the original indicators \( m_i \) and \( m_j \).

Where \( "q_{ij}, m_i" "m_j" \) are symbols in the formula

\[
q_{ij} = \frac{\sum_{k=1}^{q}(m_{ki} - \bar{m}_i)(m_{kj} - \bar{m}_j)}{\sqrt{\sum_{k=1}^{q}(m_{ki} - \bar{m}_i)^2} \sum_{k=1}^{q}(m_{kj} - \bar{m}_j)^2}. \]

(3)

In formula (3), \( \bar{x} \) and \( \bar{y} \) are the average values of i and j indices, respectively.

The characteristic value is the load of each principal component. It is an important index to measure the influence of the principal component. The larger the characteristic value is, the more sufficiently the principal component reflects the corresponding index information [12].

The variance contribution rate of the principal component is the proportion of the variance of the principal component in the total sample. The greater the variance contribution rate is, the more original variable information is carried by the principal component. The calculation formula is:

\[
f_k = \frac{\lambda_k}{\sum_{i=1}^{s} \lambda_i}. \]

(4)

The cumulative contribution rate is the amount of the original information by the first \( y \) principal components in turn: \( \sum_{i=1}^{y} \lambda_i / \sum_{i=1}^{x} \lambda_i \).
λ is the characteristic value of the correlation matrix. If the cumulative contribution rate reaches 85%, it means that this part of the principal component contains the main information needed to measure the index, that is, the principal component index is qualified. Otherwise, it needs to be eliminated.

2.3. Rough Set Method. Rough set can be simply understood as a method of dividing data. This method only needs to mine and classify the data itself, and does not need other methods to study the internal laws between the data. It can form certain classification rules, eliminate redundant information to the greatest extent without affecting the classification results, and obtain the most scientific index system.

Assuming that the index set is denoted as Q, for any index subset C of the index system, the equivalence relation (indistinguishable relation) RED(C), ∀C ⊆ R, ∀m ∈ C, (m_i, m_j) ∈ U × U, m(x_i) = m(x_j) is defined as:

\[ \text{RED}(C) = \{ (x_i, x_j) \in U \times U, \forall t \in C, (m(x_i) = m(x_j)) \} \]  
(5)

REQ(C) is the equivalent relationship corresponding to the index subset C. Assuming that C is an equivalent relation set, c ∈ C if RED(C) = RED(C – {c}), which means that c is a redundant index in C and needs to be eliminated; otherwise, it means that c is a necessary index and needs to be retained.

The specific steps for screening equivalence relationship indicators are as follows:

1. For index system Q = \{x_i\} (i = 1, ..., m), get RED(Q);
2. For i = 1, ..., m, find RED(Q – {x_i}) in turn;
3. If RED(Q – {x_i}) = RED(Q) and x_i are redundant indices in the index system Q, they can be eliminated; otherwise, x_i is a necessary index in the index system Q and cannot be eliminated;
4. Assuming that the index system after screening is SCR(Q).

\[ \text{SCR}(Q) = \{ x_i | x_i \in Q, \text{RED}(Q – {x_i}) \neq \text{RED}(Q) \} \]  
(6)

3. The Screening Process of Traction-Type Faulty Elevator Factors

3.1. Principles of Index Screening. Based on PCA and the rough set method, the principle of traction fault elevator factor index screening is shown in Figure 1.

3.2. Principal Component Analysis Method Preliminary Screening Index. The primary selection index in this article comes from the high-frequency index in the Hangzhou Special Equipment Inspection and Research Institute, Hangzhou Administration for Market Regulation, and references. In accordance with the observability principle, the indicators that are not quantified in specific ways in the primary selection indicators are deleted so that the indicators after the initial screening can be used in practice [13]. Finally, when selecting indicators, we must fully consider the specific calculation units and calculation methods of each indicator.

Using the abovementioned PCA to study the 17 indicators of the primary selection, the correlation matrix can be obtained, and x non-negative eigenvalues and their corresponding eigenvectors \[\mu_i (i = 1, 2, \cdots, x)\] can be obtained. Principal component analysis was performed on the selected 17 indicators to obtain the eigenvalues, variance contribution rate, and cumulative contribution rate of each principal component [14], as shown in Table 1.

As shown in Table 1, it shows that the cumulative contribution rate of the first four indicators is 96.247, reaching 85%, it means that the first four indicators contain the main information of all indicators, so the elevator failure rate index in the principal component is deleted [15].

The determination of the principal component index depends on the size of the component value of the index, the larger the component value is, the more it can indicate that the index is necessary. When the principal component index selected, the value of the feature vector component is not less than 0.1, indicating that the index information can be more fully reflected. According to the eigenvector analysis of the first 4 principal components, the indicators reflecting the 4 principal components are the rated load, rated speed, area, use unit, operating years, alarm time, user population, use occasion, manufacturing unit process level, maintenance unit process level, human factors, and equipment factors.

In the initial establishment of the index system, the research object and research purpose corresponding to the index must first be clarified, and then, the corresponding establishment method must be selected to obtain a comprehensive index set with a clear relationship between them. Table 2 shows the initial index system of traction fault elevator factors as follows.

3.3. Optimization of the Index System Based on the Rough Set Attributes Reduction Principle. Through the calculation of the rough set attribute reduction principle, it can be concluded that in the second-level indicators corresponding to the operating environment of the first-level indicators, there is an equivalent relationship between the area of the indicator and the user group, the classification of the user unit and the use occasion. For the indicators of the equivalent relationship, the classification result of the research object remains unchanged after excluding the user population and use occasion, so the indicator user population and use occasion are excluded from the indicator system.

After the equivalent indicators are eliminated, the indicator system is qualitatively optimized, sorted by the in-degree of the vertices, and processed from small to large to classify the indicators. PCA reduces a large number of
indicators into grouped indicators with significant statistical characteristics and checks that the decomposition of the target layer has no target crossover. As a result, the structure of the indicator system is chaotic, and the elements within the indicator system are independent of each other and do not overlap. Quantitative analysis showed that the rough set method based on the attribute reduction principle successfully screened the redundant correlation indicators of the equivalence relationship, eliminated irrelevant and unimportant indicators, and finally obtained the traction fault elevator factor index system, as shown in Table 3.

3.4. Description of Elevator’s Fault Evaluating Indexes. Based on the construction principles of the index system, combined with the construction ideas of the index system by references, starting from the objective state of the failed traction elevator, and according to the national standards of the People’s Republic of China《Safety rules of the construction and installation of electric lifts》(GB 7588-2016), combined with the rated parameters, the operating environment and the manufacturing and maintenance conditions of elevator, the traction elevator failure factor index system is described as follows (Table 4).
In this paper, starting from the perspective of failed elevator; according to the state of the failed elevator and the objective factors of operation, the traction failure elevator factor index is constructed which used the rough set theory and PCA. PCA reduces the large number of indicators into grouping indicators with significant statistical characteristics, and the rough set method, based on the principle of rough set attribute reduction, successfully screens the redundant correlation indicators of the equivalence relationship, eliminates irrelevant and unimportant indicators, and finally obtains traction and establishes a traction-type failed elevator factor index system. The combination of the AHP and the rough set method for index selection greatly reduces the problems of excessive calculation and subjectivity of

### Table 2: Initial index system of traction-type failure elevator factors.

<table>
<thead>
<tr>
<th>Target layer</th>
<th>First-level indicator</th>
<th>Secondary indicators</th>
<th>Index quantification</th>
<th>Filter results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated parameters</td>
<td>Rated load (kg)</td>
<td>&lt;1000</td>
<td>Reserve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rated speed ((m/s))</td>
<td>1000~2000</td>
<td>Reserve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of floors (floor)</td>
<td>&gt;2000</td>
<td>Reserve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Area</td>
<td>&lt;1</td>
<td>Reserve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use unit</td>
<td>1~3.5</td>
<td>Reserve</td>
<td></td>
</tr>
<tr>
<td>Operating environment</td>
<td>Operating years</td>
<td>&lt;25</td>
<td>Reserve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alarm time</td>
<td>25~48</td>
<td>Reserve</td>
<td></td>
</tr>
<tr>
<td>Manufacturing and maintenance conditions</td>
<td>Manufacturing unit process level</td>
<td>&gt;48</td>
<td>Reserve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintenance unit process level</td>
<td>Reserve</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Timeliness of maintenance</td>
<td>Reserve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Man-machine factors</td>
<td>Human factors</td>
<td>Reserve</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equipment factors</td>
<td>Reserve</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Index system of traction-type failure elevator factors.

<table>
<thead>
<tr>
<th>Target layer</th>
<th>First-level indicator</th>
<th>Secondary indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated parameters</td>
<td>Rated load</td>
<td>Rated load X1</td>
</tr>
<tr>
<td></td>
<td>Rated speed</td>
<td>Rated speed X2</td>
</tr>
<tr>
<td></td>
<td>Area</td>
<td>Area X3</td>
</tr>
<tr>
<td></td>
<td>Use unit</td>
<td>Use unit X4</td>
</tr>
<tr>
<td>Operating environment</td>
<td>Operating years</td>
<td>Operating years X5</td>
</tr>
<tr>
<td></td>
<td>Alarm time</td>
<td>Alarm time X6</td>
</tr>
<tr>
<td>Manufacturing and maintenance conditions</td>
<td>Manufacturing unit</td>
<td>Manufacturing unit X7</td>
</tr>
<tr>
<td></td>
<td>Maintenance unit</td>
<td>Maintenance unit X8</td>
</tr>
<tr>
<td></td>
<td>Timeliness of maintenance</td>
<td>Human factors X9</td>
</tr>
<tr>
<td>Man-machine factors</td>
<td>Human factors</td>
<td>Equipment factor X10</td>
</tr>
</tbody>
</table>

### Table 4: Index system of traction-type failure elevator factors.

<table>
<thead>
<tr>
<th>No.</th>
<th>Indicators</th>
<th>Description of indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rated load</td>
<td>The weight that the elevator can bear within the rated range</td>
</tr>
<tr>
<td>2</td>
<td>Rated speed</td>
<td>Elevator car running speed specified in elevator design</td>
</tr>
<tr>
<td>3</td>
<td>Area</td>
<td>Specific administrative area where the elevator is located</td>
</tr>
<tr>
<td>4</td>
<td>Use unit</td>
<td>Nature of specific elevator user</td>
</tr>
<tr>
<td>5</td>
<td>Operating years</td>
<td>Years of elevator service</td>
</tr>
<tr>
<td>6</td>
<td>Alarm time</td>
<td>Time period of elevator fault alarm</td>
</tr>
<tr>
<td>7</td>
<td>Manufacturing unit</td>
<td>The information of elevator manufacturer</td>
</tr>
<tr>
<td>8</td>
<td>Maintenance unit</td>
<td>The information of elevator maintenance</td>
</tr>
<tr>
<td>9</td>
<td>Human factors</td>
<td>Elevator users factors affecting elevator safety</td>
</tr>
<tr>
<td>10</td>
<td>Equipment factor</td>
<td>Factors of elevator itself affecting elevator safety</td>
</tr>
</tbody>
</table>

### 4. Summary

In this paper, starting from the perspective of failed elevator; according to the state of the failed elevator and the objective factors of operation, the traction failure elevator factor index is constructed which used the rough set theory and PCA. PCA reduces the large number of indicators into grouping indicators with significant statistical characteristics, and the rough set method, based on the principle of rough set attribute reduction, successfully screens the redundant correlation indicators of the equivalence relationship, eliminates irrelevant and unimportant indicators, and finally obtains traction and establishes a traction-type failed elevator factor index system. The combination of the AHP and the rough set method for index selection greatly reduces the problems of excessive calculation and subjectivity of
conventional methods, and this paper provides a new concept for index selection.

**Data Availability**

All data, models, and code generated or used during the study appear in the submitted article.

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

**References**


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