Reliability Centered Multi-objective Optimization Analysis Method for Equipment-intensive Systems

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Abstract: Aiming at the lack of foundation for the maintenance strategy of equipment-intensive enterprises. This paper is based on the analytic hierarchy process to obtain the importance of equipment in the system, which qualify the equipment operation data and expert experience data by layer. Firstly, the system is modeled according to correlation, and then the consistency evaluation matrix is constructed. Finally, the reliability ratio can be used to simplify the system model. For the equipment-intensive systems such as a metro station system, the experimental data can match well with the empirical data. This method is able to achieve reliability-centered, which can also make the system a promotion efficiency of maintenance decisions and a reduction in the cost of operation and maintenance.

Keywords: Equipment-intensive, FAHP, multi-objective optimization, reliability.

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1. Introduction

Modern manufacturing industry is characterized by complicated equipment structure, composed of mass accessories, and the features of the various unit is distinct [1]. As an important part of equipment operation, equipment criticality evaluation [2] examines the essential degree of equipment in each system, and which is one of the scientific bases for superiors to classify equipment and determine their maintenance strategies.

Equipment criticality grading involves complex conditions and factors. Firstly, it should be divided according to the hierarchical structure of the equipment system, and then it can be determined that different equipment should deal with the different influencing factors. Mathematical modeling is an important tool for solving complex engineering problems [3]. The equipment-intensive system involves a large number of associated parts, and these systems have many state variables and unknown parameters. The present situation of equipment-intensive system is filled with incomplete data, influencing factors, the empirical data is not Datamation [4]. The mathematical model can accurately represent these systems. This paper using the structured operating data and unstructured empirical data, using analytic hierarchy method to realize centered the critical degree of the intensive system of classification, and provide more simplify equipment model for maintenance policy decisions.

The traditional analytic hierarchy process (AHP) [5] is characterized by the mathematization of people's subjective judgment process, so as to make the decision more easily accepted by people themselves. It has the rigor in structure, especially it has obvious advantages in solving unstructured decision problems. However, the criticality of each device node in the equipment-intensive system is caused by different factors, reliability is generally an important index for equipment criticality grading. In some cases [6]-[8], reliability has no direct influence on the overall performance of the equipment. Then reliability may be an important factor to classify the nodes of the equipment, and it is necessary to study the reliability-centered multi-objective optimization analysis method for the equipment. At the same time, these system models are often huge and complex, which need to simplify the system equipment model by using the comprehensive critical degree of the equipment, so as to improve the decision making efficiency of equipment management and maintenance.

This paper, by using AHP is a complicated multi-objective decision problem is decomposed into multiple objectives or principles (rules, constraints), after calculating the minimum reliability index (minRI) threshold. Simplify the whole system model through the specified weight range to improve maintenance decision-making efficiency and operating costs reducing. The main contributions of this paper are as follows:

1. Estimated the lowest reliability index of equipment relative to the system, which according to the characteristics of equipment;
2. Combined with the reliability weight obtained by the analytic hierarchy process, the weight range of the simplified hierarchical model is selected to improve the maintenance decision-making efficiency and operating costs reducing;

This paper uses an example of equipment key classification of the metro station system proves that the method provided in this paper has practical engineering application value.

2. Basic Theory

2.1. Basic Theory of Multi-objective Optimization Analysis Method

The equipment-intensive system has the characteristics of complex and diverse equipment construction. There is a separation of the development and use phases of reusable equipment, low cost of operation and maintenance. Metro equipment system is such an intensive system that is made up of different institutions, such as vehicles, power supply, signal, station equipment, and other institutions. These institutions form an organic whole with a specific function, different levels of equipment interact with each other. The whole Metro equipment system can be decomposed into interrelated hierarchies. This structure can be expressed as different element layers in subsystems, modules, components, and repairable units, etc., which can reflect the correlation impact of individuals on the whole system and further determine the importance of the above elements relative to the system.

In this paper, AHP is to divide the system hierarchy to analyze element relations. The relationship between the various elements of the system tends to methodize, through mathematical method to quantify the importance of each element in the system. Then combining with the min-RI of equipment system, it provides a basis for evaluating the equipment criticality grading in the system. It's including the following three parts [5].

1) System structure decomposition

First, the equipment-intensive system is decomposed according to our research objective. All elements are grouped at different levels, such as subsystems, modules, components, and repairable units, etc., to form a system structure that can fully describe the system. This system structure is a reasonable low hierarchy structure, which contains part of the internal structure and the hierarchical structure of element relations, it should be noted that the system structure must be orderly.

2) Comparison of importance

Then, the importance of the elements of the same layer relative to the elements of the previous layer can be compared in pairs, and the comparison results can be written in the form of a comparison matrix. The number and order of the comparison results depend on the hierarchical division and complexity of the equipment-intensive system.

3) Calculation of importance

Finally, calculate the eigenvalues of the comparison matrix according to the Perron-Frobenius theory[9], where the eigenvectors corresponding to the maximum eigenvalues can reflect the importance of the corresponding hierarchical elements relative to the elements in the upper layer. The importance degree can be compared layer by layer in a top-down order, and then the importance degree of each element in each level can be normalized to weighted average to determine the importance degree of each element relative to the whole system.

2.2. Mathematical Basis

a denotes the universe of unique events; Φ denotes the index of unique events.

Suppose there are n element a_{1-n}, one of the factors affects the attributes of importance, which can be quantified as n the index Φ_{1-n}, the importance of the attribute Φ_{1-n}/Φ_{1-n} of this n element is compared in pairs, forming a matrix A of n-order, the comparison matrix is:

$$A=\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix}=\begin{pmatrix} \Phi_1/\Phi_1 & \Phi_1/\Phi_2 & \cdots & \Phi_1/\Phi_n \\ \Phi_2/\Phi_1 & \Phi_2/\Phi_2 & \cdots & \Phi_2/\Phi_n \\ \vdots & \vdots & \ddots & \vdots \\ \Phi_n/\Phi_1 & \Phi_n/\Phi_2 & \cdots & \Phi_n/\Phi_n \end{pmatrix} \tag{1}$$

This comparison matrix has four characteristics:

1) all of the above elements are non-negative, ie $a_{ij} \geq 0$;

2) the elements on the diagonal are all 1, ie $a_{ij} = 1$, where $i = j$;

3) All elements satisfy reciprocity, ie $a_{ij} = 1/a_{ji}$;

4) all elements have complete consistency, ie $a_{ij} = a_{ik}a_{jk}$.

According to the Perron-Frobenius theory: a matrix whose diagonal element is 1 and satisfying reciprocity, the maximum eigenvalue λ_{MAX} satisfies $\lambda_{MAX} \geq n$, and the corresponding eigenvector λ_{MAX} is non-negative. In particular, when the comparison matrix has full consistency at the same time, the maximum eigenvalue $\lambda_{MAX} = n$, while the remaining eigenvalues are zero.

And the column vector $\Phi = (\Phi_1, \Phi_2, \cdots, \Phi_n)^T$ has the following relationships:

$$A\phi = A(\phi_1, \phi_2, \cdots, \phi_n)^T = n\phi \tag{2}$$

Obviously, n is the eigenvalue of the comparison matrix A, the column vector A whose component is the attribute value of each element happens to be the corresponding eigenvector whose eigenvalue is n.

Since objective things are complicated and people's cognition and understanding of things are subjective, the comparison matrix established by people's subjective will may not be consistent with reality. In order to ensure the rationality of the analytic hierarchy process in practical applications, it is necessary to perform a consistency check on the obtained comparison matrix A before sorting. Suppose that the eigenvalues of the comparison matrix are respectively λ_{1-n}, where $\lambda_1 = \lambda_{MAX} = n$ and the rest of the features are 0. When the comparison matrix A does not have complete consistency, then there is a maximum eigenvalue $\lambda_{MAX} > n$, and the rest of the eigenvalues must be will satisfy formula (3).

$$\sum_{i=2}^{n} \lambda_i = n - \lambda_{MAX} < 0 \tag{3}$$

Then, the closer $\sum_{i=2}^{n}\lambda_i$ is to 0, the higher the degree of consistency of the comparison matrix A, and the average of the remaining eigenvalues except the largest eigenvalue in the comparison matrix does not deviate from the consistency index:

$$I_C = (\lambda_{MAX} - n) / (n-1) \tag{4}$$

I_C denotes the consistency indicator of the test comparison matrix. When the matrix conforms to complete consistency, then $I_C = 0$.

In practical engineering applications, it is difficult to make the comparison matrix fully conform to the actual situation. In order to determine whether the comparison matrix has satisfactory consistency, the random consistency measure I_g is introduced, and the calculation steps are as follows [10]:

Step 1: N-order identity matrices are constructed using a random method.

Step 2: The upper triangular part of the comparison matrix is filled with n scales and their reciprocals in the $1 \sim n$ scale randomly to form m random sample matrices

Step 3: The consistency index I_C of n random sample matrices is calculated, and its average value is the random consistency index I_g of n-order comparison matrix.

For the order 1-9 comparison matrix, the values I_g are shown in Table1.

Table 1. The Values of Random Coincidence Indicator

Order	1	2	3	4	5	6	7	8	9
I_g	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Therefore, it can be seen that for the comparison matrices of order 1 and order 2, I_g only has formal significance, because the comparison matrices of order 1 and order 2 are the perfect consistency. When the matrix order is more than 2, the ratio of the consistency index I_C of the comparison matrix to the random consistency index I_g of the same order is the random consistency ratio, denoted as R_C.

$$R_C = I_C / I_g \tag{5}$$

When $R_C < 0.1$ it is satisfied, it is considered that the comparison matrix is more practical and has a satisfactory consistency.

At the same time, we use a fuzzy analytic hierarchy process to solve the problem that pairwise comparison of general AHP method increases the fuzzy quantity, and limits the focus on element objects to a certain range. proposed the method of judging by comparison of trig fuzzy Numbers [11], that is:

Assuming a fuzzy number M in the theory field R, if the membership function $\mu_M(x): R \rightarrow [0,1]$ M is expressed as:

$$\mu_M(x) = \begin{cases} \frac{1}{m-x}x - \frac{l}{m-l}, x \in [l,m] \\ \frac{1}{m-u}x - \frac{u}{m-u}, x \in [m,u] \\ \\ 0, x \in (-\infty, l] \cup [u, -\infty) \end{cases} \tag{6}$$

where $l \le m \le u$, l and u represent the lower limit and upper limit of M, m is the median of the membership of M is 1, and a general triangular Fuzzy number M is expressed as (l,m,u).

Then, considering the ambiguity of the person, the triangular fuzzy number M_1, M_3, M_5, M_7, M_9 is used to represent constant (for example: 1, 3, 5, 7, 9) , and M_2, M_4, M_6, M_8 is the intermediate value.

3. Reliability Centered Multi-Objective Optimization Analysis Method

Generally, FAHP is divided into four steps: construction of the hierarchy model, construction of a fuzzy comparison matrix, ordering of the same-level elements, and overall sorting of hierarchy.

The algorithm used in this paper is shown in Fig. 1. It is mainly aimed at the characteristics of high-reliability requirements of complex systems and complex equipment structure. There are two additional steps are added in the algorithm: 1) after the fuzzy matrix is built, the minimum reliability is obtained according to the characteristics of equipment; 2)the system is simplified according to the threshold value and minimum reliability, so as to make the key equipment stand out.

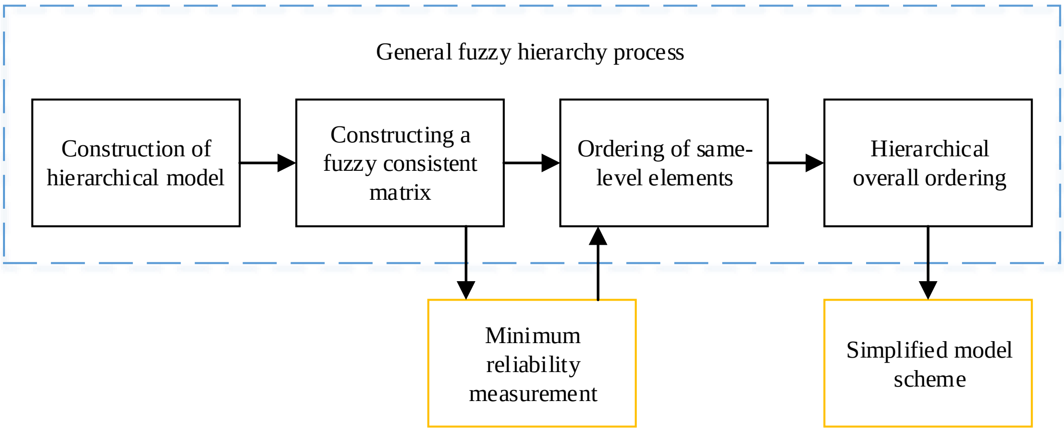

Fig. 1. Fuzzy analytic hierarchy process.

3.1. Construction of the Hierarchical Model

Conduct hierarchical analysis on the object of this article, and first make clear the scope of the system, including the influencing elements, the mutual relationship between elements, and the target to be obtained.

To establish a reasonable hierarchical structure is to organize the main factors of the decision-making problem and construct a hierarchical structure model on the premise of defining the decision-making goal. In this model, elements are divided into a target layer, a criterion layer, and a project layer based on their attributes and interrelationships, as shown in Fig.2. The contents of these levels are distributed as follows:

Target layer: This is the intended goal or ideal result found in the analysis of the decision problem, and there is only one element in this hierarchy.

Criterion layer: It contains criteria layer factors that influence the realization of the goal. The factors may be interrelated or subordinate to each other, so they need to be divided into different levels and groups.

Project layer: This level is mainly to achieve the goal of decision-making, in the middle of the analysis of alternative measures and programs. The contents of each level are defined and connected by lines to form a hierarchical structure. Furthermore, there are no restrictions on the number of elements dominated by each element in each level, but generally, there are no more than 9 elements because too many dominated elements bring difficulties to the judgment.

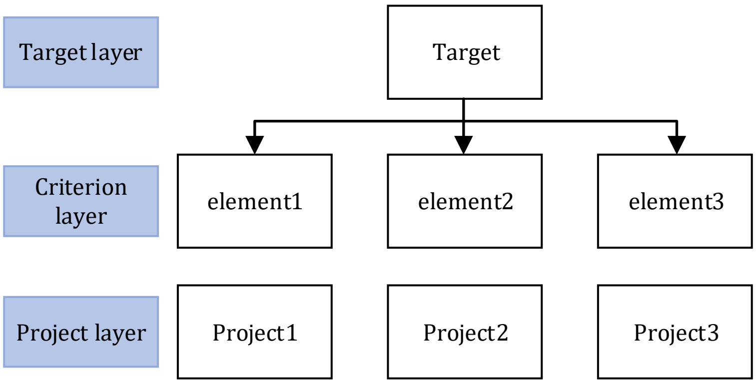

Fig. 2. Hierarchical structure.

The hierarchical model to be established in this paper is used to make a horizontal comparison of the equipment as shown in Fig. 3, which serves as the scheme layer of this study.

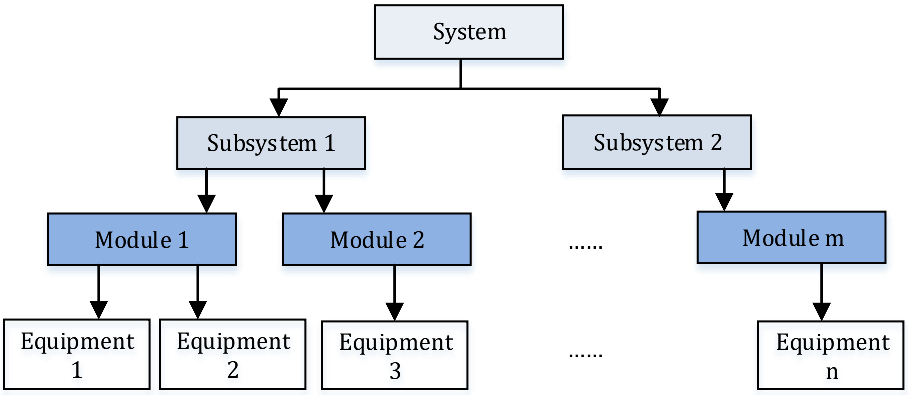

Fig. 3. Equipment structure decomposition.

3.2. Construction of Fuzzy Matrix

The hierarchy structure is composed of the relationship between factors, but the proportion of each factor in the target measurement system is not necessarily the same. The degree of impact on the realization of the target is different, which requires the determination of the importance scale of the two criteria in the judgment matrix. The main difficulty in determining the judgment matrix is that the proportion of these criterion factors is not easy to be quantified, and it is often inconsistent with the degree of importance of the decision maker's satisfaction due to insufficient consideration, and even may imply contradiction. The pairwise comparison of the factors is carried out, and then the pairwise comparison matrix is established. That is:

A: It is easier to identify differences in importance between two factors by comparing them in pairs rather than all together.

B: The relative scale is adopted to reduce the difficulty of comparing factors with different properties, so as to improve the relative accuracy.

Assuming that element a in level X is related to element b_{1-n} in level Y, the comparison matrix of elements in level Y with respect to element a is shown in equation (7).

$$A_{a-Y} = \begin{pmatrix} 0.5 & a_{12} & \cdots & a_{1n} \\ 1-a_{21} & 0.5 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1-a_{1n} & 1-a_{2n} & \cdots & 0.5 \end{pmatrix} \quad (7).$$

where the value a_{ij} represents the importance of the element a. The scoring principle of the fuzzy triangle judgment matrix is shown in Table 2.

Table 2. Scoring Principle of Fuzzy Judgment Matrix

Number	Quality
0.5	For element a, element b_i is equally important relative to element b_j
0.6	For element a, element b_i is slightly more important than element b_j
0.7	For element a, element b_i is more important than element b_j
0.8	For element a, element b_i is very important relative to element b_j
0.9	For element a, element b_i is very important relative to element b_j
0.1-0.4	The inverse comparison of the scoring principle

The scale of relative importance is the key to construct the comparison matrix and sequence the importance of the next element. After the measurement of the relative importance of elements is defined, a comparison matrix can be constructed based on the combination of object data, expert opinions, and objective facts.

In order to solve the problem of AHP consistency and repeated scoring, the fuzzy consistency matrix is constructed. The steps are as follows:

a: Sum over the column matrix

$$r_i = \sum_{k=1}^{n} a_{ik} \quad (8)$$

b: Solve for the elements of a fuzzy matrix

$$r_{ij} = \frac{r_i - r_j}{2(n-1)} + 0.5 \quad (9)$$

where r is the rank in the judgment matrix.

3.3. Minimum Reliability Measurement

When solving the minimum reliability of the solution layer, it is necessary to quantify the fault level and give the minimum acceptable reliability of the equipment. This paper plans to use the experience of equipment experts to give the corresponding weight of the severity of the failure mode, and then add the weight coefficient of the critical degree of the equipment to get the ultimate acceptable minimum reliability formula.

Severity classification of failure modes, such as reliability factors that affect subway operation: i. impact on train operation safety; II. Delay more than 15 minutes; III. 5-15 minutes later; IV. Impact on train service quality; V. no impact on train operation. Based on the experience of subway experts, the corresponding weight of severity of 5 failure modes is given, and then the weight coefficient of equipment criticality is added to get the ultimate acceptable minimum reliability formula R_r as shown in equation (10) :

$$R_r = \zeta(\frac{N-\sum_{i=1}^{5} n_i w_i}{N}, \delta(W)) \tag{10}$$

where N is the number of failures occurring within one maintenance cycle interval of the equipment, n_i is the number of failure modes, w_i is the weight of severity failure of the failure mode, and $\delta(W)$ is the weight coefficient function of equipment criticality classification.

3.4. Same Level Element Ordering

The ordering of elements at the same level is to calculate the importance and order of all thresholds in this level relative to an element at the previous level according to the comparison matrix. According to the basic mathematical analysis of the analytic hierarchy process in section 1.2 above, it can be known that the maximum eigenvalue and eigenvector of the comparison matrix of elements at the same level are the problem.

There are many ways to calculate matrix features and feature vectors. Due to the comparison matrix designed in the analytic hierarchy process has the characteristics of non-negative, diagonal elements 1 and reciprocity, this paper has a relatively simple square root method. The calculation steps are as follows:

Step 1: calculate the score for each row of elements in the matrix.

$$\Theta_i = \prod_{j=1}^{n} a_{ij}, (i = 1, 2, \cdots, n) \tag{11}$$

Step 2: calculate the n root of Θ_i

$$\overline{\Theta_i} = \sqrt[n]{\Theta_i} \tag{12}$$

Step 3: Normalize $\overline{\Theta_i} = \left(\overline{\Theta_1}, \overline{\Theta_2}, \cdots, \overline{\Theta_n}\right)^T$, which is the largest eigenvector $\Theta_i = (\Theta_1, \Theta_2, \cdots, \Theta_n)^T$.

$$\phi_i = \overline{\Theta_i} / \sum_{i=1}^{n} \overline{\Theta_i}, (i = 1, 2, \cdots, n) \tag{13}$$

Step 4: Calculate the maximum eigenvalue.

A hierarchical single ranking is to calculate the weight of each influencing factor of each judgment matrix relative to the criterion. Firstly, the importance of the weight vector W is obtained by row and normalization processing of fuzzy consistent matrix R.

$$W = (w_1, \cdots, w_n)^T \tag{14}$$

The solution formula is as follows:

$$w_i = \frac{\sum_{j=1}^{n} a_{ij} - 1 + \frac{n}{2}}{n(n-1)} \tag{15}$$

3.5. Hierarchical Global Ordering

Using the same hierarchical ordering results, you can calculate the relative importance of all elements between different hierarchies. The overall ranking of hierarchy is generally carried out according to the hierarchical structure chart of research objects from bottom to top. Assuming that all elements a_{1-n} in hierarchy X are ordered by the same level of elements and the weight value is $\lambda_{a_1-a_n}$, and the related elements of an element a_i in hierarchy Y are b_{1-n} and, b_{1-n} is proficient in the weight value $\lambda_{b_i-b_m}^{j}$ obtained by previous element ordering, then the importance of element b_i relative to hierarchy X can be calculated by equation (16).

$$\phi_{b_i-X} = \sum_{j=1}^{n} \lambda_{a_j} \lambda_{b_i}^{j}, (i=1,2,\cdots,n) \tag{16}$$

The consistency of a single comparison matrix is judged by the random consistency ratio of the matrix. For objects composed of multiple levels, the overall ranking consistency index and random consistency index are obtained through the weighted average of the consistency index of the comparison matrix of each level. Assuming that the weight $\lambda_{a_1-a_n}$ obtained by sorting all elements a_{1-n} in the hierarchy X, and the consistency index and random consistency index of comparison matrix corresponding to element a_i are I_{C_i} and I_{g_i}, then the consistency index and random consistency index of overall ranking of hierarchy can be calculated by equation (17).

$$I_C^* = \sum_{i=1}^{n} \lambda_{a_i} I_{C_i}, I_g^* = \sum_{i=1}^{n} \lambda_{a_i} I_{g_i} \tag{17}$$

The relative random consistency ratio is calculated by equation (18).

$$R_C^* = I_C^* / I_g^* \tag{18}$$

As with the single comparison matrix, when a+B, the overall ranking results are considered to have satisfactory consistency.

3.6. Simplified Model Scheme

Combined with the minimum reliability obtained in section 3.3, we directly classified the scheme layer into high-reliability requirements and low-reliability requirements and sorted the same layer elements obtained in section 3.4, corresponding to the importance ratio corresponding to the model simplification. For example, if a system has a high degree of importance and reliability, its corresponding importance proportion threshold is set to 100%, and if a system has a low degree of importance and reliability, its corresponding importance proportion shall comply with the expectation of the importance of each factor.

4. Station System Test Example

4.1. Object Description

This section takes a station equipment of metro as an example to verify the multi-objective optimization analytic hierarchy process method proposed in this paper. For example, the equipment structure of the escalator system is shown in figure 4. In addition to the obvious equipment such as floorboard, handrail belt, ladder, ladder chain and drive control host, there are hundreds of kinds of professional equipment including various subsystems, modules, and minimum maintainable units. So the selection of the station equipment for this article research content accord with intensive this requirement, and metro industry itself has a relatively perfect equipment management method can provide a more complete expert experience and data, the following design experiments to verify reliability-centered equipment-intensive system multi-objective optimization of hierarchical analysis method have the function of the reliability of choice and the effectiveness of the model is simplified to improve the efficiency of decision making.

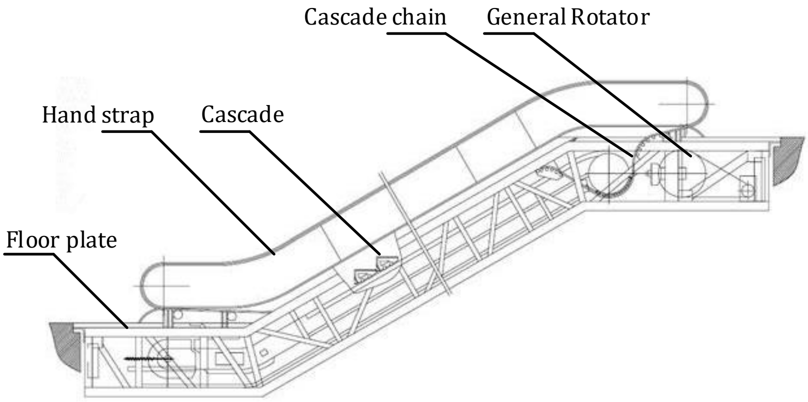

Fig. 4. Simple structure of escalator equipment.

4.2. Analyze and Simplify Results

The escalator equipment structure shown in Fig.4 is hierarchically decomposed according to the steps in chapter 3 of this article. It is found that there are 44 nodes in the escalator system that can be marked as P_n. After comprehensive consideration of the correlation and inclusion relationships of the system structure, the hierarchical structure is established as shown in Fig. 5.

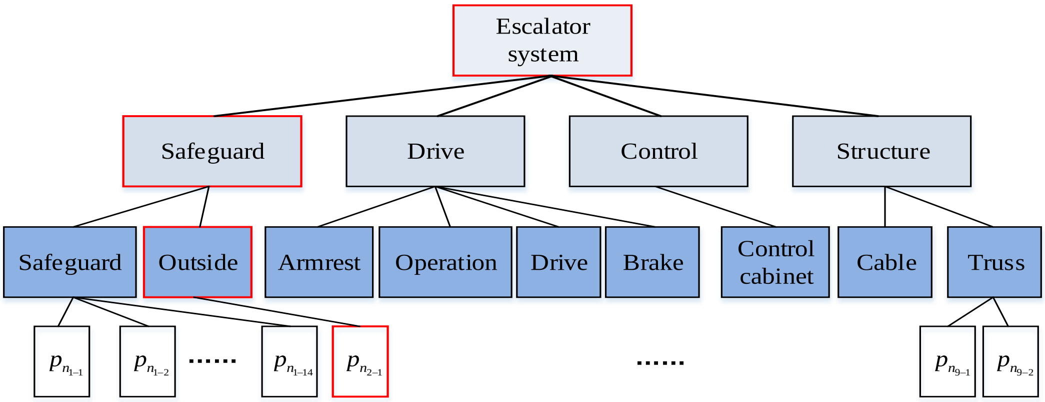

Fig. 5. Hierarchy structure of escalator equipment.

Then, according to the important analysis, three professionals of this major are required to score the key factors of the equipment according to the actual situation of each professional equipment. According to the results of the first stage escalator scoring four factors subsystem layer selected, the module layer four factors in selecting components from four factors, minimum maintenance unit layer selected four factors, of each layer equipment compared to each other, escalator professional in each work according to Table 3 shows metrics, construct a total of 16 judgment matrix, based on the hierarchy analysis diagram as shown in Fig. 6 equipment-intensive system stratification.

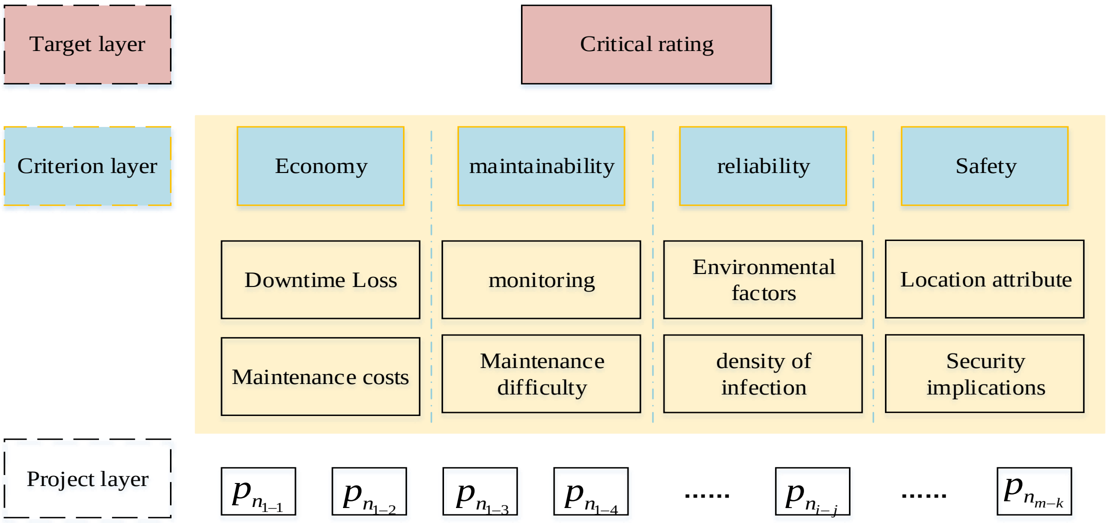

Fig. 6. Hierarchy analysis for equipment-intensive systems.

The criteria layer is defined as follows.

Monitor ability: refers to the operation status of the system, the operation key information, the degree of transparency of the business call process, and the degree of information acquisition, output, and transfer.

Maintenance difficulty: refers to the probability of restoring the system to its original operating efficiency under the specified maintenance conditions and within the specified maintenance time in the maintainable system.

Environmental factor: refers to the influence degree of the environmental state of the equipment on the equipment.

Safety impact: refers to the degree of damage caused by equipment failure to safety accidents.

Hazard degree: refers to the comprehensive hazard degree of equipment failure.

Shutdown loss: the amount of loss caused by equipment shutdown. (breakdown and shutdown losses are divided into two parts: maintenance and replacement costs -- direct losses; Accident loss -- indirect loss)

Maintenance cost: refers to the cost of maintenance consumables and labor hours incurred during the whole operation of the equipment.

Position representation: refers to the degree of critical difference between different positions of the same equipment in the system. (for example, different positions of a device in the same system have large critical differences, or different positions of the device in the system have small critical differences)

According to the measurement standards given in Table3, the judgment matrix is constructed, such as the subsystem level of escalators to score each criterion, and finally, the results are formed as shown in Table3.

That is, the judgment matrix is:

$$A_{e-s} = \left\{ \begin{vmatrix} 0.5 & 0.5 & 0.6 & 0.2 & 0.2 & 0.3 & 0.3 & 0.6 \\ 0.5 & 0.5 & 0.6 & 0.2 & 0.2 & 0.3 & 0.3 & 0.6 \\ 0.4 & 0.4 & 0.5 & 0.1 & 0.1 & 0.2 & 0.2 & 0.5 \\ 0.8 & 0.8 & 0.9 & 0.5 & 0.5 & 0.6 & 0.6 & 0.9 \\ 0.8 & 0.8 & 0.9 & 0.5 & 0.5 & 0.6 & 0.6 & 0.9 \\ 0.7 & 0.7 & 0.8 & 0.4 & 0.4 & 0.5 & 0.5 & 0.7 \\ 0.7 & 0.7 & 0.8 & 0.4 & 0.4 & 0.5 & 0.5 & 0.8 \\ 0.4 & 0.4 & 0.5 & 0.1 & 0.1 & 0.3 & 0.2 & 0.5 \end{vmatrix} \right\}$$

Table 3. Results of the Escalator Subsystem

Criterion layer/matrix	Monitor ability	Mainten-ance difficulty	Environ-mental factor	Safety impact	Hazard degree	Shutdow-n loss	Mainten-ance cost	Position represen-tation
Monitor ability	0.5	0.5	0.6	0.2	0.2	0.3	0.3	0.6
Maintenance difficulty	0.5	0.5	0.6	0.2	0.2	0.3	0.3	0.6
Environmental factor	0.4	0.4	0.5	0.1	0.1	0.2	0.2	0.5
Safety impact	0.8	0.8	0.9	0.5	0.5	0.6	0.6	0.9
Hazard degree	0.8	0.8	0.9	0.5	0.5	0.6	0.6	0.9
Shutdown loss	0.7	0.7	0.8	0.4	0.4	0.5	0.5	0.7
Maintenance cost	0.7	0.7	0.8	0.4	0.4	0.5	0.5	0.8
Position representation	0.4	0.4	0.5	0.1	0.1	0.3	0.2	0.5

Element tree sort, then, according to the comparison matrix, can draw the escalator subsystem layer criterion (monitoring, maintenance easy, safe, environmental factors, harm degree, stop loss, maintenance costs, location) of the normalized sorting weight respectively = [0.09949, 0.09864, 0.085943, 0.16636, 0.17670, 0.14727, 0.14229, 0.08300], the variance σ of 0.0014 , the average threshold for 0.1264 ($E+\sigma$).

This can represent fault hazard degree of reliability of expert scoring weight 0.1767 > 0.1264, which means that the escalator subsystem of equipment reliability demand is higher. According to the weighted ranking criterion layer: Hazard degree, Safety impact, Shutdown loss, Maintenance cost, Monitorability, Maintenance difficulty, Environmental factor, Position representation. Hazard degree of the most important indicator, The first four indicators accounted for more than 60% (weight), on the escalator importance sort subsystem of equipment, process to construct judgment matrix as above.

Results of overall ranking of system hierarchy and equipment importance can be obtained: safety protection system, drive system, control system, structure =[0.2561, 0.2618, 0.2167, 0.2654], the sequence from high to low is:structure , drive system, safety protection system, control system. Because of high-reliability requirements, so the equipment is not simplified, take ε=100% subsystem equipment.

By analogy, respectively for the escalator module layer, component layer, layer for minimum maintenance unit element tree sort, because failure harm degree weight is higher, damage degree, security implications, stop loss, maintenance costs four criteria to do importance ranking factors accounted for more than 60% (weight), with all the subsystem of equipment as a layer information, after we have the important degree of grading equipment, equipment maintenance strategy decision making. Overall arrangement of hierarchy is obtained, the sequence of equipment arrangement from high to low is: brake, drive, run, truss, safety protection, handrail, control cabinet, cable, external. Part layer equipment order: main drive sprocket and shaft, main drive chain, lower end sprocket and shaft, host seat, reducer box, motor, coupling. Minimum maintainable unit layer equipment sequence: main shaft bearing, host fixed, coil, reducer box bearing, motor bearing, elastic pin rubber. Therefore, due to the high-reliability requirement of the above escalator equipment nodes, the escalator equipment nodes of station equipment are not omitted.

Table 5 shows the number of nodes of model simplification after the importance classification of professional equipment of escalator, AFC, screen door and environmental control system, respectively. The reliability requirements of AFC and environmental control systems are low, so the importance threshold value is ε=90%, which simplifies the nodes to 53% and 47% respectively. For the maintenance of intensive equipment systems, the method provided in this paper provides maintenance professionals with a scientific significance classification method, and the most important is to improve the decision-making efficiency by simplifying the model.

Table 4. Comparison of Elevator, AFC, Screen Door and Environmental Control System in the Algorithm

	Elevator	AFC	Screen door	Environmental Control System
The quantity before simplification	44	32	35	45
The quantity after simplification	44	17	35	21

As can be seen from Table2, the consistency ratio R_C of all comparison matrices in equation (18) is less than 0.1, and all of them have satisfactory consistency.

5. Conclusion

This paper presents a multi-objective optimal analytic hierarchy process (ahp) with reliability as the center. , through intensive system hierarchy structure, the method to compare various elements in the system relative to the higher level of importance, and then quantitative system through mathematics and sorting, the importance of each element in the use of reliability index in the process of sorting decision, the final selection reliability-centered weight range, can be part of the model in the secondary device node and reduction model variables, and reduce the end, the intensive system modeling and maintenance decision-making has certain engineering application value.

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