Research on the Maintenance Effectiveness Evaluation of Electronic Information Equipment

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Abstract. An effectiveness evaluation model is provided considering the construction of effectiveness index system, index weight distribution and evaluation algorithm to help evaluate the electronic information equipment's maintenance support effectiveness. The analysis results of an example demonstrate that the model effectively validates the effectiveness, reliability and consistency of the electronic information equipment's maintenance support. Thus, it can work as the scientific basis of selections on the electronic information equipment's maintenance support methods.

1. Introduction
Nowadays, the focus of research on the evaluation of maintenance effectiveness of electronic information equipment at home and abroad is the effectiveness of electronic information equipment's maintenance support, the evaluation method, the optimized model of spare parts and the evaluation of maintenance support capability [1]. However, no thorough researches have been conducted into the choices and effectiveness evaluation of electronic information equipment's maintenance support method, a perfect, normative and highly operational mechanism of evaluation on electronic information equipment's maintenance support method is urgently needed. Therefore, to address the effectiveness evaluation of electronic information equipment's maintenance method, the evaluation index system of maintenance effectiveness should be constructed; proper methods should be used to evaluate the efficiency of different maintenance support methods; the efficiency, reliability and consistency of electronic information equipment's maintenance support method is validated to promote the efficiency of electronic information equipment's maintenance support and to provide support for the scientific decisions of choices of electronic information equipment's maintenance support method.

2. Evaluation Model of Maintenance Effectiveness
The maintenance effectiveness evaluation of electronic information equipment in this paper, whose evaluation object is the maintenance methods of electronic information equipment, is the process that evaluates the comprehensive effectiveness of maintenance support method in electronic information equipment in complex and varied conditions. The support abilities of electronic information equipment's maintenance method are evaluated with scientific and reliable methods to see to what extent they cater to users' needs.

The proposed evaluation model is shown in figure 1.
Firstly, an index system that suits electronic information equipment maintenance effectiveness is constructed; secondly, index weight is determined with the analytic hierarchy process (AHP) and entropy method; thirdly, relevant evaluation model is built with fuzzy integrated evaluation; at last, the effectiveness, reliability and consistency is verified by an example.

3. Construction and Weight Allocation of Evaluation Index System

The evaluation index system not only connects experts and objects, but also bridges methods and objects. The robustness of the model and reliability of conclusions is guaranteed by scientific and fair conclusions that come from scientific, reasonable and objective evaluation index system [2]. Thus, the establishment of scientific and reasonable evaluation index system is the key for the success of evaluation of maintenance effectiveness in electronic information equipment. Following the principles of science, comprehensiveness, completeness, applicability, simplicity, and the combination of qualitative and quantitative indicators, summarizing documents and consulting experts' advices, not only an index system that caters to the actual needs of evaluation of maintenance effectiveness in electronic information equipment is built with the help of evaluation factors of maintenance effectiveness in electronic information equipment, but also index weight enjoys scientific allocation with AHP-ENTROPY weight analysis.

2.1. Construction Factors of Index System

The process of electronic information equipment maintenance, which is an organic synthesis of complex activities, covers all the procedures that are needed in the electronic information equipment maintenance. It involves not only physical elements such as maintenance support agencies, repair personnel, maintenance equipment and maintenance facilities, but also activity elements such as equipment maintenance and repairing, activity supply and support [3]. Evaluation of maintenance support effectiveness in electronic information equipment not only involves the numbers and skills of equipment maintenance personnel, the maintenance support costs and the choices of maintenance support methods, but is also closely connected with the adaptability of the equipment to the external
environment and internal system, the complexity of the equipment itself and the security and confidentiality requirements. Focusing on the characteristics of electronic information equipment maintenance support, the electronic information equipment maintenance effectiveness index system is built from the timeliness, applicability, adaptability, reliability and safety by drawing lessons from the relevant research results of domestic and foreign scholars in the evaluation of maintenance support efficiency [4-7]. It is shown in Table 1.

Table 1. Evaluation Index System of Electronic Information Equipment Maintenance Effectiveness.

| First level index    | Secondary index           | Third level index                     |
|----------------------|---------------------------|---------------------------------------|
| Timeliness (B1)      | Processing time (C11)     | Travel expenses (D11)                 |
|                      | Diagnosis time (C12)      | Condition construction cost (D12)     |
|                      | Repair time (C13)         | Equipment maintenance cost (D13)      |
|                      |                           | Annex fee (D14)                       |
| Applicability (B2)   | Costs (C21)               | Maintenance personnel number (D21)    |
|                      | Matching device complexity (C22) | Maintenance personnel capacity (D22) |
|                      | Maintenance support force (C23) |                                   |
| Adaptability (B3)    | Environmental adaptability (C31) |                                   |
|                      | System adaptability (C32) |                                       |
| Reliability (B4)     | Repairing rate (C41)      |                                       |
|                      | Prevention efficiency (C42) |                                       |
|                      | Delay rate (C43)          |                                       |
| Security (B5)        | Data security (C51)       |                                       |
|                      | Document security (C52)   |                                       |
|                      | Component part security (C53) |                                   |

2.1. The Index Weight Determination Based on AHP-ENTROPY Weight Analysis

The methods used to determine the weight of performance evaluation indexes mainly include: analytic hierarchy process, subjective assignment, objective assignment, combination assignment, principal component analysis, ENTROPY weight and so on. The analytic hierarchy process is widely used. However, this method is subject to great subjective influence of experts in the construction of judgment matrix, which tends to cause the results of index weight not to conform to the reality. ENTROPY weight analysis is to determine the weight coefficient of the index according to the difference degree of the index value. It is an objective weight analysis method, but it lacks the application of prior knowledge of experts. Obviously, analytic hierarchy process and ENTROPY weight analysis are complementary. Therefore, this paper proposes to combine them to determine the index weight coefficient, and the basic process is shown in Figure 2.

The main steps are as follows:

1. Judgment matrix should be constructed. Based on Delphi method, experts were invited to fill in the significance analysis table of indicators. In the questionnaire, the next level of indicators belonging to the same level in the index system is compared in pairs to determine the importance of each element in the level relative to the upper level of indicators. In order to vividly demonstrate the importance of each element, the commonly used 1-9 or 1-9 reciprocal scale is shown in the paper [8], and a judgment matrix $A$ is established.

2. The product $M_i$ of the elements in each row of the judgment matrix $A$ is calculated as equation (1).
\[ M_i = \prod_{j=1}^{n} a_{ij}, i = 1,2,\ldots,n \] (1)

The \( n \)th root \( \overline{W}_i \) of \( M_i \) is calculated as equation (2).

\[ W_i = \frac{\overline{W}_i}{\sum_{i=1}^{n} W_i} \] (2)

Then, \( W = [w_1, w_2, w_3, \ldots, w_n]^T \) is the feature vector.

The largest eigenvalue \( \lambda_{\text{max}} \) is calculated as equation (3).

\[ \lambda_{\text{max}} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \] (3)

where, \( (AW)_i \) means the number \( i \) element of vector \( AW \).

Feature vector \( W = [w_1, w_2, w_3, \ldots, w_n]^T \) is calculated as equation (4).

\[ AW = \lambda_{\text{max}} W \] (4)

After the normalization of feature vectors, the weight of each index relative to its own index can be obtained.

(3) Consistency check. In order to make the judgment matrix \( A \) have the general consistency and logical rationality, the maximum eigenvector \( \lambda_{\text{max}} \) is used to test the consistency of the judgment matrix. The following calculation is conducted as equation (5).

\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} \] (5)

The value of average random consistency index \( RI \) is shown in table 2.

| Order | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|-------|----|----|----|----|----|----|----|----|----|
| \( RI \) | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

when \( n = 1,2 \), \( A \) must be consistent, and \( RI \) is meaningless; when \( n > 2 \), and \( CR \) meets the requirements of equation (6).

\[ CR = \frac{CI}{RI} < 0.10 \] (6)

Thus, if the data meets the requirements, then the weights obtained are valid; otherwise, matrix optimization is carried out.

(4) The ENTROPY method modifying the index weight. ENTROPY is used to measure the amount of information carried in an indicator, \( x_{ij} (i = 1,2,L,n; j = 1,2,L,m) \) is the evaluation data of indicator \( j \) from expert \( i \). For the given \( j \), the smaller the ENTROPY value \( x_{ij} \) is, the more inconsistent the data is, and less information will appear, the greater impacts \( x_{ij} \) will have on the object [9]. The steps of determining the correction factor by ENTROPY weight analysis are as follows:
1) Establish the correction matrix. The scoring levels of each indicator can be quantified with specific numerical values and scored by n experts according to the quantitative criteria [9,10], [8,9], [7,8], [6,7], [0,5].

2) The characteristic proportion of the \( i \) th evaluation object of the \( j \) th indicator is calculated as equation (7).

\[
p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, \quad x_{ij} \geq 0 \quad \text{and} \quad \sum_{i=1}^{n} x_{ij} > 0
\]

3) ENTROPY of indicator \( j \) is shown as in equation (8).

\[
e_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij})
\]

\( k > 0, e_j > 0, k = \frac{1}{\ln n} \). If \( x_{ij} \) is equal to all the \( j \), then \( p_{ij} = \frac{1}{n} \), and \( e_j = k \ln n \).

4) Difference coefficient \( x_{ij} \) is calculated. For \( j \), the more different the numerical value of \( x_{ij} \) is, the smaller the numerical value of \( e_j \) is, the greater impacts the indicator will have on evaluation object. When numerical value of \( x_{ij} \) is the same, \( e_j = e_{\max} = \ln(\frac{1}{\ln n}) \), indicator \( x_{ij} \) will have no impacts on the evaluation object. Thus, the definition of coefficient of difference is shown as equation (9).

\[
g_j = 1 - e_j
\]

5) Index weight is adjusted. As shown in equation (10), the index weight \( w_j \) is multiplied by \( g_j \).

\[
a_j = w_j \times g_j
\]

The revised index weight coefficient is \( \bar{a}_j = a_j / \sum_{j=1}^{m} a_j \) by normalization.

6) Synthetic weight. The composite weight mainly considers the impact of each underlying indicator on the evaluation target. In the electronic information equipment maintenance efficiency index system, the weight vector of interlayer \( B = \{B_1, B_2, B_3, B_4, B_5\} \) to top layer \( A \) is \( W_A = \{W_{B_1}, W_{B_2}, W_{B_3}\} \). Likewise, weight vector of indicator \( C_{i1}, C_{i2}, L, C_{im} \) of \( B_i \) in layer C is \( W_{B_i} = \{W_{c_{i1}}, W_{c_{i2}}, W_{c_{im}}\} \). Then, Synthetic weight of \( C_{i1}, C_{i2}, L, C_{im} \) to \( A \) is \( WC_{i1}, WC_{i2}, L, WC_{im} \). \( WC_{ij} \) is shown as equation (11).

\[
WC_{ij} = W_{B_i} W_{C_j}, \ j = 1, 2, \cdots, m
\]

Meanwhile, the consistency check as shown in equation (12) is needed.

\[
CR = \frac{\sum_{i=1}^{m} W_{R_i} C_{IJ}}{\sum_{i=1}^{m} W_{R_i} R_{IJ}}
\]
$C.I_i$ means the compatibility factor of $C_{i1}, C_{i2}, L, C_{im}$ to $B_i$, and $R.I_i$ is the Random consistency factor of $C_{i1}, C_{i2}, L, C_{im}$ to $B_i$. When $CR<0.10$ in equation (12), the composite weight meets the requirements, otherwise the comparison matrix needs to be optimized.

4. Selection of Evaluation Methods
The evaluation of maintenance efficiency of electronic information equipment belongs to multi-index comprehensive evaluation. Comprehensive evaluation methods of multi-index system usually include AHP, fuzzy comprehensive evaluation method, data envelopment method, grey relational analysis method, extension comprehensive evaluation method, TOPSIS method, etc. As the evaluation parameters of electronic information equipment maintenance efficiency involve a wide range of levels and the correlation between the data is small, it is not suitable to use the grey correlation evaluation method for evaluation. The TOPSIS method is mainly used for qualitative analysis of indicators and to rank the pros and cons. It lacks the reliability of qualitative analysis, and the subjective role of AHP is obvious. Some factors that are difficult to quantify in the maintenance efficiency index of electronic information equipment are quantified, and a comprehensive evaluation decision is made for a variety of factors. The fuzzy relation synthesis principle and fuzzy set theory are used to comprehensively evaluate factors [10]. To sum up, this paper adopts the fuzzy comprehensive evaluation method to evaluate the maintenance efficiency of electronic information equipment.

5. Evaluation Example
Thus, the evaluation model established in this paper is used to evaluate and analyze the maintenance effectiveness of three commonly used methods for electronic information equipment maintenance support, namely: (1) Maintenance personnel repairs faulty equipment through diagnosis; (2) Go back to the factory for modular replacement repair; (3) Call the repair shop to repair the faulty equipment parts and original parts. Based on the evaluation index system of electronic information equipment maintenance efficiency and the calculation method of index weight coefficient proposed in the third part, taking timeliness $B_1$ as an example, the difference correction factor $B_1$ is obtained by using the ENTROPY method:

$$g_B = [0.8063 \ 0.7946 \ 0.8039]$$

The index weight obtained by AHP method is:

$$w_B = [0.159 \ 0.244 \ 0.236]$$

The weight of each index is multiplied by the corresponding difference correction factor to obtain the final result after the weight is corrected:

$$W_B = [0.1594 \ 0.2416 \ 0.2361]$$

Similarly, the specific results of each indicator are shown in table 3.

Table 3. Weight Coefficient of Maintenance Performance Evaluation Index of Electronic Information Equipment.

| The first level indicators | Weight coefficient | The secondary indicators           | Weight coefficient | Synthetic weight |
|----------------------------|--------------------|------------------------------------|--------------------|-----------------|
| Timeliness (B1)            | 0.3456             | Processing time (C11)              | 0.1594             | 0.0551          |
|                            |                    | Diagnosis time (C12)               | 0.2416             | 0.0682          |
|                            |                    | Repair time (C13)                  | 0.2361             | 0.0835          |
|                            |                    | Cost (C21)                         | 0.2838             | 0.0611          |
|                            |                    | Matching the complexity of the device | 0.2828             | 0.0608          |
| Applicability (B2)         | 0.3327             |                                    |                    |                 |
Taking the maintenance personnel's method of repairing the faulty equipment through diagnosis as an example, according to the steps of fuzzy comprehensive judgment, the following indicator evaluation matrix set can be obtained:

5.1. Fuzzy Judgment Matrix of First Level Index \( A \)

\[
R_A = \begin{bmatrix}
0.2 & 0.3 & 0.5 & 0 & 0 \\
0 & 0.4 & 0.3 & 0.3 & 0 \\
0.2 & 0.6 & 0.2 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 \\
0.4 & 0.5 & 0.1 & 0 & 0 \\
0.2 & 0.8 & 0 & 0 & 0 \\
0.3 & 0.4 & 0.3 & 0 & 0 \\
0.5 & 0.4 & 0.1 & 0 & 0 \\
0.2 & 0.8 & 0 & 0 & 0 \\
0.3 & 0.5 & 0.2 & 0 & 0 \\
0.1 & 0.7 & 0.2 & 0 & 0 \\
0.2 & 0.6 & 0.1 & 0 & 0 \\
0 & 0.4 & 0.3 & 0.3 & 0 \\
0.1 & 0.3 & 0.5 & 0.1 & 0
\end{bmatrix}
\]

5.2. Fuzzy Judgment Matrix of Secondary Indicator

\[
R_{B_1} = \begin{bmatrix}
0.2 & 0.3 & 0.5 & 0 & 0 \\
0.1 & 0.6 & 0.2 & 0.1 & 0 \\
0.8 & 0.2 & 0 & 0 & 0
\end{bmatrix},
R_{B_2} = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
0.4 & 0.5 & 0.1 & 0 & 0 \\
0.3 & 0.4 & 0.3 & 0 & 0
\end{bmatrix},
R_{B_3} = \begin{bmatrix}
0.5 & 0.4 & 0.1 & 0 & 0 \\
0.2 & 0.8 & 0 & 0 & 0
\end{bmatrix},
R_{B_4} = \begin{bmatrix}
0.3 & 0.5 & 0.2 & 0 & 0 \\
0.1 & 0.7 & 0.2 & 0 & 0 \\
0 & 0.2 & 0.7 & 0.1 & 0
\end{bmatrix},
R_{B_5} = \begin{bmatrix}
0.1 & 0.3 & 0.5 & 0.1 & 0
\end{bmatrix}
\]

To sum up, the fuzzy evaluation matrix of each index of the method can be obtained. According to \( B = W_A \times R \), the fuzzy comprehensive evaluation can be calculated. The evaluation values of each factor are shown as follows:

\[
E_{R_1} = [90.80.60.50.30] \times W_{R_1} \times R_{R_1} = 79.33
\]
\[
E_{R_2} = [90.80.60.50.30] \times W_{R_2} \times R_{R_2} = 83.24
\]
\[
E_{R_3} = [90.80.60.50.30] \times W_{R_3} \times R_{R_3} = 80.00
\]
\[
E_{R_4} = [90.80.60.50.30] \times W_{R_4} \times R_{R_4} = 74.16
\]
\[
E_{R_5} = [90.80.60.50.30] \times W_{R_5} \times R_{R_5} = 69.64
\]

Finally, the comprehensive effectiveness evaluation of this method is as follows:
\[ E_A = [90,80,60,50,30] \times W_A \times R_A = 76.06 \]

With the same model and indicator system, the final result of the other two methods (return to the factory to repair the modular replacement; call the factory to repair faulty equipment parts or original parts) is 67.05 and 75.03, respectively.

According to the evaluation process and the results of the three methods, the following conclusions can be drawn:

1. Timeliness is crucial to the maintenance performance of electronic information equipment. According to the index weight assignment results, maintenance time (0.0835), diagnosis time (0.0682) and other factors account for a large proportion in the maintenance efficiency index system of electronic information equipment, which have a great impact on the maintenance efficiency of electronic information equipment. Therefore, in order to give full play to the maintenance support efficiency of electronic information equipment, attention should be paid to the timeliness of maintenance support to shorten the diagnosis time and maintenance time.

2. The safety of maintenance support means needs to be improved urgently. The weight of security is the lowest in all the first level indicators, only 0.0847, but in today’s society, electronic information equipment is undergoing a digital, networked, intelligent transformation. It is imminent to ensure the safety of the equipment information data, and in the process of transportation, equipment data safety and security are also important components. The efficiency of equipment maintenance support in electronic information can’t be greatly improved without considering various safety factors.

3. Maintenance personnel who repair the faulty equipment through diagnosis has the highest comprehensive efficiency. This would require the maintenance staff not only have high maintenance skills, but also have a wealth of knowledge reserves, not only to master the use of a variety of equipment maintenance methods, but also can accurately judge the electronic information equipment failure. Therefore, the personnel engaged in the industry need to keep pace with the times, and had better experience cross major training, learning network management, remote diagnosis and treatment, the Internet of things, such as artificial intelligence, big data and other new and high technologies.

6. Conclusions
In view of the lack of research on the effectiveness evaluation of the maintenance support methods of electronic information equipment and the lack of pertinence of the evaluation model, this paper proposes a set of indexes system applicable to the maintenance effectiveness evaluation of electronic information equipment based on the research results of equipment maintenance support effectiveness evaluation. AHP and ENTROPY weight analysis are used to determine the index weight coefficient. By comparing the advantages and disadvantages of each comprehensive evaluation method and combining the characteristics of the maintenance efficiency of electronic information equipment, a method combining fuzzy comprehensive evaluation method and the analytic hierarchy process is selected to evaluate the maintenance efficiency of electronic information equipment. In the end, three methods of maintenance efficiency are analyzed with practical examples and the evaluation results are obtained. The optimal method is found, which plays a certain reference role in the research of maintenance efficiency of electronic information equipment.

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