

Quality Evaluation of Equipment Maintenance Process Based on Interpretive Structure Model

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Abstract. Based on the "5M1E" analysis method, the maintenance process quality evaluation system was established, and then the interpretive structure model (ISM) was used to analyze the hierarchical relationship of the influence of each index factor on the maintenance process quality, and the rationality of the ISM model analysis method was verified through the analytic hierarchy process. The results show that maintenance equipment and facilities A4, assembly process A5 and spare parts quality A7 are surface factors of maintenance process quality. Raw material A3 and maintenance personnel A2 are the middle-level factors of maintenance process quality; Maintenance management system A1 and maintenance environment A6 are the deep factors of the quality of maintenance process, and are the influential factors to focus on and improve. In addition, the corresponding maintenance suggestions are given for each factor, which provides theoretical guidance for the formulation of equipment maintenance management procedures.

Keywords: Interpretive structure model; Equipment maintenance; Process quality; 5M1E; index factor.

1. Introduction

Equipment maintenance quality evaluation is an important means to improve maintenance quality and ensure maintenance efficiency [1-2]. By analyzing the pros and cons of the maintenance process, the key factors affecting the maintenance quality are determined, and then according to these factors, targeted and reasonable maintenance management procedures are formulated, which can improve the maintenance quality and efficiency of equipment, improve the working performance and service life of equipment, and avoid unnecessary waste of resources to reduce maintenance costs. Therefore, it is necessary to construct the quality evaluation system of equipment maintenance process with appropriate analysis methods, and further provide theoretical guidance for maintenance programs.

ISM is a structured model building method. Its modeling idea is to split a complex system into several influential elements, and then explore the relationship between these elements through model [3-4]. The method presents the analysis results in the simplest hierarchical topology diagram, which has strong intuitiveness and can clearly show the causal hierarchical relationship between the elements. Therefore, it is often used to study a variety of complex engineering problems, such as construction risk analysis [5], equipment performance testing [6] and improving work efficiency [7].

Based on the "5M1E" analysis method, this paper determines the index factors that affect the quality of equipment maintenance process and establishes the evaluation index system of maintenance process quality. Then, ISM method is used to explore the hierarchical relationship between the factors affecting the quality of maintenance process, which provides a theoretical basis for the establishment of equipment maintenance procedures.

2. Factors affecting the quality of maintenance process

In practical engineering, the "5M1E" analysis method is usually used to evaluate and manage product quality, and "5M1E" refers to six factors affecting product quality. Namely, human factor,

Machine factor, Material factor, Method factor, Measurement factor and Environment factor [8]. In the field of industrial manufacturing, as long as the "5M1E" principle is strictly followed and these six factors are effectively controlled within the allowable range, high-quality products can be efficiently obtained [9]. It can be seen that although the structure of military equipment is complex, high technical content and comprehensive, the "5M1E" analysis method can also be used for maintenance quality management assessment, so as to reduce costs and improve performance. Therefore, the index factors used in this study to evaluate the quality of maintenance process are constructed on this basis.

2.1. Human Factor

The maintenance of any equipment requires manual operation, even the most advanced automation equipment in the event of failure, still need to manually troubleshoot, repair and replacement of spare parts. In other words, the human factor is the most direct and the most important factor among the many influencing factors. The technical level of maintenance and management personnel is not up to standard, the sense of responsibility is poor, the concept of safety is weak, the level of operation is low, and the illegal operation will have a great negative impact on the quality of equipment maintenance. In addition, the management of unreasonable production management plans, wrong personnel arrangements and low standards of product inspection will reduce the quality of equipment maintenance.

2.2. Machine Fctor

"Machine" refers to a variety of maintenance equipment used in the maintenance process, which mainly includes monitoring instruments, tooling, fixtures, molds and templates. For equipment maintenance, the accuracy and precision of maintenance equipment directly affect the quality of equipment maintenance. Therefore, the advanced degree of various mechanical equipment and testing devices used in the maintenance process and the perfection of maintenance support material resources affect and restrict the maintenance quality of equipment to a great extent.

2.3. Material factor

"Materials" refers to the raw materials used in the maintenance process and the spare parts required to replace the faulty parts. The quality problems or defects of raw materials and spare parts not only affect the quality of maintenance products, but also endanger the lasting use and stable operation of products. Therefore, the supplier of raw materials and spare parts needs to develop the corresponding quality requirements assurance agreement, and it is also necessary to conduct quality inspection before use.

2.4. Method factor

"Materials" refers to the raw materials used in the maintenance process and the spare parts required to replace the faulty parts. The quality problems or defects of raw materials and spare parts not only affect the quality of maintenance products, but also endanger the lasting use and stable operation of products. Therefore, the supplier of raw materials and spare parts needs to develop the corresponding quality requirements assurance agreement, and it is also necessary to conduct quality inspection before use.

2.5. Measurement factor

"Measurement" means whether the methods used to detect performance parameters during maintenance are reasonable, standard and correct. This requires the maintenance manager to make clear the purpose and accuracy of the measurement task in advance before the measurement work, so as to determine a reasonable measurement method and select a measuring instrument with the right accuracy. To ensure the accuracy of the measurement results, all measuring equipment should be checked and calibrated regularly.

2.6. Environment factor

"Environment" means that the environmental conditions (temperature, humidity, dust, etc.) around the equipment during maintenance will have a certain degree of impact on the maintenance work. This factor not only directly affects the state of the equipment itself, the support and maintenance of maintenance resources, but also affects the physiology and psychology of maintenance personnel, and then affects the maintenance quality of equipment.

2.7. Evaluation System

Based on the above influencing factors and with reference to the relevant literature on equipment maintenance [10], the quality evaluation index system of equipment maintenance process is constructed. A is used to represent the quality evaluation factor system of maintenance process, and the factors contained in the system are numbered sequentially, as shown in Figure 1.

3. Model construction

The modeling idea of ISM model is to divide a complex system into multiple influencing factors, and then re-establish a multi-level model [11]. The resulting model can simplify a complex problem or system, then clearly show the interactions between subsystems, and find the key factors directly related to the goal expectations. The specific modeling process is as follows:

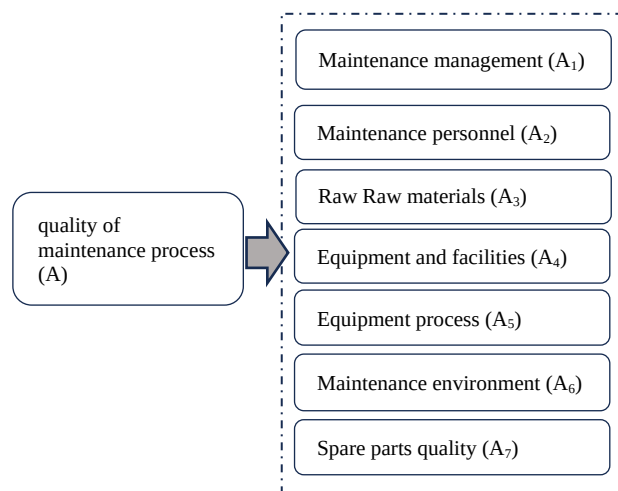


Figure 1. Schematic diagram of maintenance process quality evaluation system.

3.1. Establish the adjacency matrix

adjacency matrix is used to describe whether there is a direct relationship or mutual influence between various parts in a system. If a system contains n elements, and these elements are combined into a set, you can use $S = \{S_1, S_1, S_3, \dots, S_n\}$, then the adjacency matrix is shown as follows:

$$A = \begin{matrix} S_1 \\ \vdots \\ S_n \end{matrix} \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

The a_{ij} in matrix A follows the following definition:

$$a_{ij} = \begin{cases} 1 & S_i \text{ has influence on } S_j \\ 0 & S_i \text{ has no influence on } S_j \end{cases} \quad (2)$$

In section I, the composition of maintenance process evaluation system has been described, that is, factors affecting the quality of maintenance process mainly include maintenance management system

A1, maintenance personnel A2, raw materials A3, maintenance equipment and facilities A4, assembly process A5, maintenance environment A6 and spare parts quality A7. The data in the adjacency matrix are summarized, as shown below.

Tab. 1 Adjacency Matrix Data

	A1	A2	A3	A4	A5	A6	A7
A1	0	1	0	0	1	0	0
A2	0	0	1	1	0	0	1
A3	0	0	0	0	0	0	1
A4	0	0	0	0	1	0	0
A5	0	0	0	1	0	0	0
A6	0	1	1	1	0	0	1
A7	0	0	0	0	0	0	0

According to the data in Table 1, the adjacency matrix is constructed as follows:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (3)$$

3.2. Calculate the reachability matrix

If the Matrix is $(A+I)^k$, $k=1,2,3,\dots$, where I is the identity matrix, then $M = (A+I)^k$ is called the Reachability Matrix. According to matrix A , the reachable matrix obtained by calculation is as follows:

$$M = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

3.3. Divide the hierarchical relationship of each factor

In the reachable matrix R , find the elements that can be influenced by A_i , the elements that can influence A_i , and the consistent elements that can both influence and be influenced by A_i . In the reachable matrix R , the set of elements that can be affected by A_i is called the reachable set and is represented by $R(A_i)$. Similarly, the set of elements that affect A_i is called the antecedent set and is represented by $Q(A_i)$. The intersection of the two, that is, the elements in $C = R \cap Q$ can both influence and be influenced by A_i .

Tab. 2 Reachable set, antecedent set, and common set

	R	Q	$C=R \cap Q$
A_1	1, 2, 3, 4, 5, 7	1	1
A_2	2, 3, 4, 5, 7	1, 2, 6	2
A_3	3, 7	1, 2, 3, 6	3
A_4	4, 5	1, 2, 4, 5, 6	4,5
A_5	4, 5	1, 2, 4, 5, 6	4,5
A_6	2, 3, 4, 5, 6, 7	6	6
A_7	7	1, 2, 3, 6, 7	7

In the reachable matrix, the levels of factors are classified according to $R(A_i) \cap Q(A_i) = C(A_i)$, and the results are shown in Table III.

Tab. 3 Hierarchical Decomposition Result

Hierarchy	Factor
First	A_4, A_5, A_7
Second	A_3
Third	A_2
Fourth	A_1, A_6

Table III shows the hierarchical decomposition of each element. The factors of the first level are the fundamental purpose of the quality evaluation system, the factors of the next level are the causes of the factors of the upper level, the factors of the upper level are the results of the factors of the next level, and the factors of the lowest level are the initial causes of the quality evaluation system.

3.4. Result

The relationship between the factors in Table III is presented in the form of a logical graph.

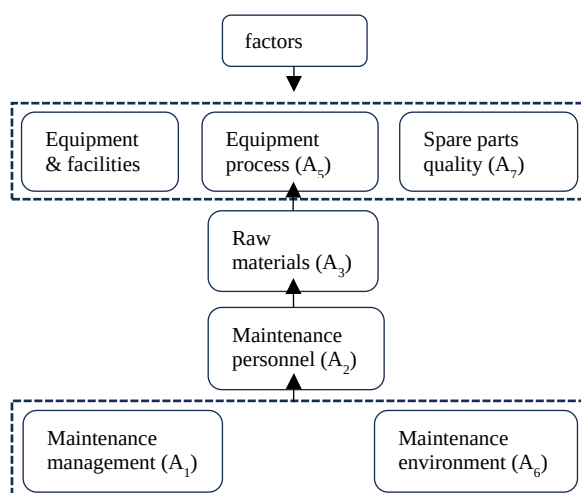


Figure 2. Interpret the structure illustration.

As can be seen from Figure II, [1] maintenance equipment and facilities A_4 , assembly process A_5 and spare parts quality A_7 are at the first level of ISM model, that is, surface factors that directly affect the quality of maintenance process, which directly reflect the level of maintenance process and are susceptible to high-level factors. [2] Raw material A_3 and maintenance personnel A_2 belong to the second and third layers of ISM model respectively, that is, the middle-level factors affecting the quality of maintenance process, which can act on surface factors and be affected by deep factors. [3] Both maintenance management system A_1 and maintenance environment A_6 belong to the fourth layer of ISM model, that is, the deep factors affecting the quality of maintenance process. These factors are at the highest level and need to be considered and improved.

Through the analysis of quality index factors of maintenance process, it can be seen that maintenance equipment and facilities A_4 , assembly process A_5 and spare parts quality A_7 directly affect the quality of maintenance process. This indicates that if you want to directly improve the maintenance quality of equipment, you must consider the characteristics of the maintenance objects and maintenance equipment, ensure the adequate supply of maintenance materials and resources, and at the same time, you should scientifically evaluate the equipment and facilities and spare parts required for equipment maintenance, and reasonably formulate the required assembly process.

For the assembly process, it is necessary to strengthen the research of maintenance operation procedures and maintenance technology, clarify the principle of process selection, standardize the assembly procedure, and unify the maintenance method, so as to improve the maintenance

performance. For the quality of spare parts, when carrying out maintenance quality management, the characteristics of maintenance objects should be considered to ensure the perfection of maintenance support material resources and ensure the good quality of spare parts. The use of 3D printing technology can realize the rapid production of equipment components, and even the on-site manufacturing of damaged parts. At present, domestic universities have developed the "battlefield environment additive manufacturing maintenance support system", the application of this system, so that the damaged equipment can be repaired in a very short time.

Raw material A3 and maintenance personnel A2 are the middle-level factors affecting the quality of maintenance process. For raw materials, the required types and demand should be scientifically estimated, and the storage, supply, use and management of raw materials should be done well. Equipment maintenance personnel, as the specific implementers of maintenance and maintenance, should strictly abide by maintenance regulations and process regulations, and implement technical standards. An excellent maintenance personnel usually has a good ideological and political quality, technical quality, physical quality, which requires the equipment department to strengthen the education and training of maintenance personnel.

The bottom layer of the structure is maintenance management system A1 and maintenance environment A6, indicating that they are the fundamental factors affecting the quality of maintenance process and need to be focused on and improved. Perfect and reasonable maintenance management system is the basis to ensure the quality of the maintenance process, which has clear regulations and requirements for each factor, and strictly follow the maintenance process and standards of the maintenance management system, which can ensure the maintenance quality and improve efficiency. The traditional view tends to ignore the impact of the environment, but the model structure shows that in the design and manufacturing stage of the equipment, the adaptability of the equipment to the environment should be improved, and the harsh environment will also lead to measurement deviations and accelerated aging of parts materials. At the same time, environmental factors have a certain impact on the physical and psychological of maintenance personnel, which indicates that a comfortable working environment can not only improve efficiency but also ensure the maintenance quality of equipment to a certain extent.

4. Verification

After the text In order to verify whether the factors influencing the quality of equipment maintenance process analyzed based on ISM are reasonable, this study further uses hierarchical analysis to evaluate these index factors.

Analytica Hierarchy Process is a fast and effective hierarchical weight decision analysis method proposed by T.L. Saaty, an American operations research scientist. The method is to decompose the complex decision-making problem into multiple levels or objectives, and then determine the weight coefficient of each factor through pair-wise comparison of the index factors of each level. The weight coefficient is evaluated by experts, and the relative importance of each indicator is quantified by standard rules on a scale of "1~9", as shown in Table 4.

Tab. 4 Analytic Hierarchy Process Scale Meaning Comparison Table

value	means
1	two factors are of equal importance when compared
3	former is slightly more important than the latter
5	former is significantly more important than the latter
7	former is more important than the latter
9	former is much more important than the latter
2, 4, 6, 8	represents the median value of the above neighboring judgments
	If the ratio of the importance of factor i to factor j is a_{ij} , then the ratio of the importance of factor j to factor i is $a_{ji} = 1/a_{ij}$

4.1. Solution procedure

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

(1) Establish the hierarchical structure model.

(2) Score the weight of a single parameter: experts in the corresponding fields determine the impact of each second-level indicator on the first-level indicator through pairwise comparison of each influence factor at the same level and reference to the scale meaning in Table IV.

(3) Construct judgment matrix: According to the expert's score results, combined with the scale meaning table, the corresponding scale is assigned to each factor. The value b_{ij} obtained after comparison of different factors is filled into the row i and column j of the matrix.

$$= \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \quad (5)$$

(4) Consistency check: The purpose of this step is to determine whether the constructed matrix can be regarded as a consistent matrix, which, in contrast to a positive reciprocal matrix, satisfies the following properties: $b_{ik} = b_{ij} \times b_{jk}$, each row (or column) of the matrix multiplied by a certain number yields the same result as the elements of the other rows (or columns).

The parameter CR is used to judge the gap between the constructed judgment matrix and the consistency matrix. If CR is less than 0.1, the matrix is considered to be a judgment matrix that meets the requirements.

$$CR = \frac{CI}{RI} \quad (6)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (7)$$

λ_{max} is the maximum eigenvalue of the judgment matrix, and n is the order of the matrix.

Tab. 5 N-Ri Comparison Table

n	1	2	3	4	5	6	7
RI	0	0	0.52	0.89	1.12	1.26	1.36

(5) Computed weight vector: the influence weights of each element are calculated according to the arithmetic average method, where $i = 1, 2, \dots, n$.

$$w_i = \frac{(\prod_{j=1}^n a_{ij})^{\frac{1}{n}}}{\sum_{k=1}^n (\prod_{j=1}^n a_{kj})^{\frac{1}{n}}} \quad (8)$$

4.2. Analysis of influencing factors to the maintenance quality based on Analytic hierarchy process

The analysis above shows that the factors affecting the quality of maintenance process mainly include maintenance management system A1, maintenance personnel A2, raw materials A3, maintenance equipment and facilities A4, assembly process A5, maintenance environment A6, and spare parts quality A7. Based on these factors, the quality evaluation index system of equipment maintenance process constructed is shown in Figure I.

According to the meaning of value in Table IV, the corresponding evaluation scale is obtained through pairwise comparison of various factors affecting the overall goal. The judgment matrix obtained by summarizing them is shown in Table VI.

Tab. 6 Data Set Table

A	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	A ₇
A ₁	1	5	3	4	6	2	4
A ₂	1/5	1	3	3	4	1/6	2
A ₃	1/3	1/3	1	2	3	1	4
A ₄	1/4	1/3	1/2	1	2	1/5	1
A ₅	1/6	1/4	1/3	1/2	1	1/4	1/2
A ₆	1/2	6	1	5	4	1	3
A ₇	1/4	1/2	1/4	1	2	1/3	1

Turn the data in the above table as a matrix:

$$B = \begin{bmatrix} 1 & 5 & 3 & 4 & 6 & 2 & 4 \\ 1/5 & 1 & 3 & 3 & 4 & 1/6 & 2 \\ 1/3 & 1/3 & 1 & 2 & 3 & 1 & 4 \\ 1/4 & 1/3 & 1/2 & 1 & 2 & 1/5 & 1 \\ 1/6 & 1/4 & 1/3 & 1/2 & 1 & 1/4 & 1/2 \\ 1/2 & 6 & 1 & 5 & 4 & 1 & 3 \\ 1/4 & 1/2 & 1/4 & 1 & 2 & 1/3 & 1 \end{bmatrix} \quad (9)$$

In order to ensure that the judgment matrix has satisfactory consistency, the consistency test is carried out. Based on Matlab software, the maximum eigenvalue of the judgment matrix A is 7.7783, and the order of the matrix is 7, so the value of the calculated parameter CI is 0.1297. According to formula (6) and Table 5, CR is 0.095, which is less than 0.1, indicating that this matrix is a judgment matrix that meets the requirements.

On the basis of the judgment matrix, the influence weights of each index factor are calculated based on formula (8), as shown in Table VII.

Tab. 7 Weigh of Factors

factor	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	A ₇
weigh	0.271	0.165	0.144	0.065	0.037	0.253	0.066

AHP method is used to evaluate and analyze the quality of equipment maintenance process, and the influence weight of each index factor is obtained. The results show that the weight ratio of maintenance management system A1 and maintenance environment A6 is relatively high, which indicates that these two indicators are the key factors affecting the quality of maintenance process, which is basically the same as the results obtained by ISM model. Therefore, the rationality of ISM model analysis method for quality evaluation of equipment maintenance process is verified by AHP method.

5. Conclusion

This paper uses the "5M1E" analysis method to explore the factors affecting the quality of equipment maintenance process, and then builds the evaluation index system of equipment maintenance process quality based on these index factors, and uses the ISM model to analyze the causal hierarchical relationship between the factors affecting the quality of maintenance process, so as to understand the influence degree of each factor. The results show that the related influencing factors of maintenance process quality can be divided into 4 levels, including maintenance management system A1 and maintenance environment A6 essential factors. Not only that, but also for each factor, the corresponding equipment maintenance management suggestions are given, which provides a reliable theoretical guidance for the formulation of equipment maintenance procedures, and has a very important reference value.

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