Research on Safety Evaluation Technology of Portal Cranes Based On Analytic Hierarchy Process (AHP) Theory

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Abstract: This paper introduces the present situation of portal crane and the shortcomings of the current standard system, and puts forward a feasible safety evaluation method. Based on the theory of Analytic Hierarchy Process (AHP), the safety assessment method of portal crane is studied, and a more perfect method is put forward. The evaluation value D of equipment safety performance obtained by this method can specifically and clearly express the actual status and risk level of equipment.

1. Introduction

The Portal crane is mainly used for loading and unloading containers on shore [1]. Because of its high operating efficiency, it is widely used in ports and docks. Currently, there are many container overhead cranes in use in Shanghai. Some cranes have serious aging problems. The service life of some cranes is more than 30 years, and the design life is usually about 20 years. The safety certification of in-service portal cranes is only limited to simple enterprise self-inspection and national legal supervision and inspection, and it is impossible to identify and classify risk equipment levels. Quite a lot of equipment works under huge risks, which can easily lead to safety production accidents.

2. The safety evaluation method of portal cranes

2.1. Comparison of Common Safety Evaluation Methods

At present, Table 1 introduces some mature methods for safety assessment of special equipment. The structure of portal crane is clear, and the relative importance of each component is easy to qualitatively judge. However, quantitative judgment requires a huge amount of data. In the professional field, the weighted evaluation method is called the basis of safety assessment of wharf crane.

2.2. Weighted Evaluation Based on AHP Theory

Analytic hierarchy process (AHP) is a method of representing complex problems with ordered hierarchical structure chart proposed by Professor Sadie of University of Pittsburgh. It can express a complex problem as an ordered hierarchy diagram, and get the relative importance of the factors that affect the core problem of the whole process through specific calculation, so as to get the evaluation value of the problem [4].
As shown in Fig 1, the top layer of Figure T is called the target layer, which refers to the problem that needs to be analyzed; the bottom layer is called the lowest layer, which refers to the basic factors that cause the problem and cannot be subdivided. The layer between T and a is called the intermediate layer, which represents all the intermediate steps that cause the problem [5].

The experts score the importance of each influencing factor that constitutes the logical structure model according to a certain method, and perform data processing to obtain the result of the importance of each influencing factor to the target layer T.

Table 1. Several mature methods in current safety assessment [2-3]

| Method                        | Basal Principle                                                                 | Representative Methods                          | Application and Characteristics                      |
|-------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------|-----------------------------------------------------|
| Index Assessment Method       | According to the assessment object, the assessment items are selected, and the scoring range of the assessment items is determined according to specific principles. Professional assessment personnel score each assessment item, and the total score is calculated through exponent arithmetic. | Dow’s method and Mond method                      | Mainly applicable to the assessment of energy conversion involved in production |
| Fault tree analysis           | System safety assessment technology based on probabilistic risk analysis        | Fault tree analysis                               | Mainly applicable to the aerospace industry and emerging high-tech industries |
| Bayes Net Method              | On the basis of numerical analysis, Bayesian network is introduced into fault tree analysis | Fuzzy Analytical Method, Fuzzy Probability Method | Applicable to the real-time dynamic assessment of production systems, and require a very high calculation cost |
| Weighted Evaluation Method    | Through modeling and quantification of evaluation problems, the required safety indicators are obtained | AHP (Analytic Hierarchy Process) Method           | It has a wide range of applications, especially in the absence of necessary statistical data. |

![Hierarchical Model Diagram](image-url)
3. Research on safety evaluation of portal crane based on AHP theory

3.1. The Hierarchical Division of Portal Cranes Safety Evaluation Model
By analyzing the comprehensive characteristics of the gantry crane, we divide the crane into four safety performance levels (as shown in Fig 2).

![Fig2. THE SKETCH MAP OF SAFETY EVALUATION OF PORTAL CRANES](image)

3.2. The Determination of Weights Value of the Evaluation Indexes

1) Establishing the comparison matrix and obtaining the largest feature vector
After the crane safety evaluation model is established, by solving the maximum eigenvector of the comparison matrix between evaluation indexes, the degree of influence of each evaluation index on the relevant evaluation index of the higher level is obtained. The values of the comparison matrix are obtained by experts on a scale of 1-9 (as shown in Table 2) \(^6\). Experts express the relative importance of the evaluation indicators of bridges spanning cranes.

| Scaling | Implications                                      |
|---------|--------------------------------------------------|
| 1       | Two factors are equally important after comparison |
| 3       | The former factor is more important after the comparison between two factors |
| 5       | The former factor is obviously important after the comparison between two factors |
| 7       | The former factor is remarkably important after the comparison between two factors |
| 9       | The former factor is extremely important after the comparison between two factors |
| 2, 4, 6, 8 | The intermediate value in the above comparisons |

The relative importance of each factor in the next level relative to the factor in the previous level is determined by 1-9 numbers. The comparison matrix shown in Table 3 can be used to express the scale expression. Use the sum-product method to find the maximum eigenvector of the matrix T, thereby obtaining the importance coefficient \(\omega (\omega=0.566, 0.242, 0.192)\) of the second layer to the target layer T.

![Table 3. The comparison matrix of second layer factors to target layer T](image)

2) The consistency verification of the comparison matrix
In order to ensure that the relative importance of each component expressed by professionals on a 1-9 scale is reliable. According to AHP theory, only when the random consistency ratio of each comparison matrix \(C_r\) is less than 0.10 can the consistency of comparison matrix be verified. And the maximum characteristic root of the comparison matrix \(\lambda_{\text{max}}\) can be obtained by Eq.1:

\[
\lambda_{\text{max}} = \sum_{i=1}^{n} \frac{(\Lambda^i_{\text{max}})}{\text{max}} (i = 1, 2, \ldots, n) \tag{1}
\]
The comparison matrix consistency index CI is shown in Eq.2:

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \quad (2) \]

The comparison matrix average random consistency index RI can be obtained by the RI order table, and the matrix random consistency ratio CR can be expressed as:

\[ CR = \frac{CI}{RI} \quad (3) \]

According to Eq.1, the maximum eigenvalue of the matrix \( t \) is \( \lambda_{\text{max}} = 3.024 \), CI = 0.012, and the value of the third-order matrix (RI = 0.58) can be obtained from the RI order table. Therefore, according to Eq.3, CR can be calculated by \( CR = 0.02 < 0.10 \), so the consistency of matrix \( t \) is acceptable.

In order to establish the safety evaluation model of portal crane based on AHP theory, it is necessary to calculate the CR values of other matrices. If each CR value is less than 0.10, the model is established.

4. The safety property assess value \( D \) and the range definition

Through the inspection of the equipment, the inspectors will score each index of the equipment (the full score is 100 points). After normalizing all the indexes, the real-time state score \( I \) of each index is obtained, and the D value of crane safety performance evaluation value \( D \) is calculated through equation 4. In order to understand the real-time safety status and risk level of crane.

\[ D = \sum_{i=1}^{n} \omega_i * I_i \quad (4) \]

Through gathering experts' opinions, in the continuous feedback and modification, when the experts' opinions are basically consistent, the safety status and required measures are defined according to different \( D \) values in Table 4. The larger the \( D \) value is, the safer the whole machine is.

| \( D \) value | safety states | required measures |
|--------------|---------------|-------------------|
| >0.85        | Slight risk   | The whole machine runs well |
| 0.65≤\( D \)≤0.85 | Low risk      | There is a small fault in the whole machine. The fault points should be inspected regularly and the damaged parts should be repaired |
| 0.45≤\( D \)≤0.65 | moderate risk | The fault of the whole machine is serious, so it should be considered to make relevant repair plan and repair timely |
| 0.25≤\( D \)≤0.45 | High risk     | Shutdown and overhaul |
| <0.25        | Extreme risk  | The whole machine should be scrapped |

5. Conclusion

This paper presents a safety assessment method for portal crane, which is based on Analytic Hierarchy Process, and the following conclusions are drawn through research:

In view of the characteristics of in-service portal cranes and the imperfect supervision system, the risk level of the crane can be identified through the feasible and effective safety assessment of the portal crane.

Based on the study of safety evaluation of weighted analytic hierarchy process (AHP), a safety evaluation method for in-service gantry crane is established, and the real-time state and risk level are represented by safety evaluation index \( D \). Equipment, which provides a way for the supervision and management of equipment.

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