Research on Comprehensive Evaluation Method of Belt Conveyor

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Abstract. In order to reduce the influence of human subjectivity on the evaluation results in the process of equipment evaluation, a comprehensive evaluation method of belt conveyor combined with Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) is proposed. The AHP method is used to determine the impact weights of the belt conveyors. The FCE method is used to comprehensively evaluate the overall operation of the belt conveyor. The rationality and reliability of the proposed method for the comprehensive evaluation of the belt conveyor are verified by an example of operating parameters of a steel enterprise.

1. Introduction
As the most convenient and stable transportation tool in various industries, belt conveyors are more and more widely used due to their low energy consumption, large transportation volume and stable transportation. However, due to the current characteristics of long-distance transportation, increased transportation volume, and high speed, the requirements for the comprehensive performance of the belt conveyor itself are getting higher and higher. In order to ensure the safety and efficient work of people and equipment, in addition to the requirements of the equipment itself, it is necessary to monitor the health of the operating state in real time.

The equipment comprehensive evaluation methods mainly include principal component analysis, analytic hierarchy process, fuzzy evaluation and neural network. Many scholars have developed new comprehensive evaluation models based on this. Based on the previous studies, this paper uses the Analytic Hierarchy Process combined with Fuzzy Comprehensive Evaluation (AHP-FCE) to monitor the real-time status of the belt conveyor and give the evaluation results of the health of the equipment. First, this model need to determine the indicator evaluation system for the belt conveyor. Then, the AHP is used to stratify the indicators, eliminating the shortcomings of subjective evaluation in the past, and giving objective weights to each indicator of the equipment. Finally, the FCE is combined with the determined index weights to give the evaluation results.

2. AHP-FCE

2.1. Indicator evaluation system
The belt conveyor has a complicated structure and there are many parts to be monitored in actual operation. Because the belt conveyor needs to monitor many measuring points, heavy workload, and
high detection accuracy, it is generally impossible to check and eliminate the fault through the human sensory organs and engineering experience. The indicator evaluation system of the belt conveyor is the basis for real-time evaluation of equipment health. According to the expert knowledge and the design process of the equipment itself, the influencing factors are listed. According to the nature of the indicators, they are layered into the target layer A, the criterion layer B, and the indicator layer C, as shown in Table 1.

| Target layer A | Criteria layer B | Indicator layer C |
|---------------|-----------------|------------------|
| B1. Motor driven | C11. Front bearing temperature | C1. Motor current |
|                | C12. Rear bearing temperature |                  |
|                | C13. Vibration intensity |                  |
| A. Belt conveyor evaluation overall target | C14. Bearing vibration |                  |
|                | C15. Coil temperature |                  |
|                | C16. Motor current |                  |
| B2. Tape body | C21. Load |                  |
|                | C22. Belt speed |                  |
|                | C23. Runoff |                  |
|                | C24. Tape temperature |                  |
| B3. Working environment | C31. Ambient temperature |                  |
|                | C32. Environment humidity |                  |
|                | C33. Smoke concentration |                  |
|                | C34. Dust concentration |                  |
| B4. Maintenance costs | C41. Failure time |                  |
|                | C42. Repair time |                  |
|                | C43. Fault frequency |                  |
|                | C44. Usage frequency |                  |

2.2. AHP

The AHP proposed by Satty is easy to be accepted by people because it is consistent with people's way of thinking, and has been widely used in various decision-making problems. The AHP classifies the factors involved in the decision-making problem into target layer, criterion layer and indicator layer. After the hierarchical structure is established, a multi-level evaluation model is formed. After establishing the multi-level evaluation model, the subordinate relationship of each element between the upper and lower levels can be determined. The elements of each level in the multi-level model should be compared with the elements of the previous level in order to establish a judgment matrix. The form of the judgment matrix is shown in Table 2.

| Target layer A | Criteria layer B | Indicator layer C |
|---------------|-----------------|------------------|
| B1. Motor driven | C11. Front bearing temperature | C1. Motor current |
|                | C12. Rear bearing temperature |                  |
|                | C13. Vibration intensity |                  |
|                | C14. Bearing vibration |                  |
|                | C15. Coil temperature |                  |
|                | C16. Motor current |                  |
| B2. Tape body | C21. Load |                  |
|                | C22. Belt speed |                  |
|                | C23. Runoff |                  |
|                | C24. Tape temperature |                  |
| B3. Working environment | C31. Ambient temperature |                  |
|                | C32. Environment humidity |                  |
|                | C33. Smoke concentration |                  |
|                | C34. Dust concentration |                  |
| B4. Maintenance costs | C41. Failure time |                  |
|                | C42. Repair time |                  |
|                | C43. Fault frequency |                  |
|                | C44. Usage frequency |                  |

Judgment matrix $A - B = (b_{ij})_{mn}$ has the following properties:

1. $b_{ij} > 0$;
2. $b_{ij} = 1 / b_{ji}$;
3. $b_{ii} = 1$;

Where $b_{ij}$ represents the scale of importance of the element $B_i$ compared to $B_j$. When performing a pairwise comparison of elements, the 1-9 scale method is usually used. After the judgment matrix is established, the subsequent hierarchical ordering is performed and the consistency check is performed to find the maximum eigenvalue $\lambda_{max}$ of the judgment matrix established by each layer index relative to the previous layer index and its corresponding normalized eigenvector. The normalized components of the feature vector are the single-sequence weights of the
The relative importance of the layer index to the upper evaluation index [7].

The consistency check is to prevent an unconventional situation, for example: X is more important than Y, Y is more important than Z, and Z is more important than X. The inspection process is as shown in equation (1) and equation (2).

\[ C_I = \frac{j_{\text{max}} - n}{n - 1} \]  
(1)

\[ C_R = \frac{C_I}{I_R} \]  
(2)

When \( C_R < 0.1 \), the judgment matrix is considered to have good consistency, otherwise the value of the judgment matrix element should be adjusted. The values of the random consistency indicator \( I_R \) is shown in Table 3.

| \( n \) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \( I_R \) | 0   | 0   | 0.58| 0.9 | 1.12| 1.24| 1.32| 1.44| 1.45|

Since the evaluation result is affected by all the indicators, it is necessary to calculate the combined weight of the lowest level indicator to the total target after calculating the weight of each single-sequence index, and the combined weight is the finalized index influence weight \( W \).

2.3. FCE

The FCE method uses the idea of fuzzy mathematics to establish an analytical model, and comprehensively evaluates complex evaluation objects to obtain quantitative evaluation results. It has the advantages of clear structure, clear purpose, and strong system. It can be used to deal with some problems that are difficult to quantify and have ambiguity. Therefore, it is widely used in many fields.

The steps of the FCE are:

1. Establish a set of indicators: the set of indicators \( U \) is a set of elements that affect the object of judgment, and \( U = \{ u_1, u_2, \ldots, u_n \} \).

2. Establish an evaluation set: The evaluation set \( V \) is a set of elements that the judges may make on the judges as a set of elements, \( V = \{ v_1, v_2, \ldots, v_n \} \).

3. Construct a single-index membership function: An important step in FCE is to accurately construct the membership function, and fuzzify the index parameters in the evaluation index, starting from a single indicator in the indicator set \( U \), and the degree function determines the degree of membership of each element in the indicator set relative to the evaluation set, and obtains the evaluation matrix \( R \).

In this paper, the evaluation factor \( U \) is subjected to four levels of fuzzification, which are classified into healthy, good, general and dangerous. Since the intermediate value of the level interval is the most ideal state value, the membership of the intermediate value is determined to be "1". On this basis, the membership function is determined as shown in figure 1 [8].

![Membership function curve](image)

\[ f(x) = \begin{cases} 
1, & x \leq Z1 \\
\frac{x-Z1}{Z2-Z1}, & Z1 < x < Z2 \\
0, & x \geq Z2
\end{cases} \]  
(3)
Finally, the fuzzy evaluation result $s = w \cdot R$ is obtained, which is the combined weight vector obtained by the analytic hierarchy process. Finally, the overall evaluation result is determined according to the principle of maximum membership degree.

3. Example verification analysis

Based on the research of the above health state assessment algorithm, the three-stage conveyor belt conveyor of JSBX Steel Company is taken as an example, and the operating parameters of several time points are randomly selected. The parameters are measured by the corresponding observation sensors on the belt conveyor equipment. Since the parameters of the equipment running have fluctuations, the parameters of a single time point do not reflect the overall operating condition of the equipment, so the parameters of several time points are averaged. At the same time, if there are several measuring points with the same name and the degree of importance is equal, the average value should also be treated. Taking the sample period of 3 min as sampling, ten samples, 30 min, were selected as the observation period, and the samples were extracted, and the average value was taken for each index. Get a set of data: $[66,83.5,0.34,1500,42,3.7,3600,3.1,0,46,26.5,42,10,25,7,3,5,15]$

The name of the measuring point corresponding to the data is in accordance with figure 1, in which the deviation signal of the belt conveyor is a switching signal, so the number of sensor triggers is taken as the evaluation standard. In this example, the belt conveyor has a deviation signal of 0. The average time to failure and average repair time are the average monthly time of the year. The judgment matrix is established and the index weights are calculated, and the consistency of the obtained index weights is tested according to equation (1) and equation (2). The A—B judgment matrix is shown in Table 4.

| A  | B1 | B2 | B3 | B4 |
|----|----|----|----|----|
| B1 | 1  | 3  | 7  | 5  |
| B2 | 1/3| 1  | 3  | 2  |
| B3 | 1/7| 1/3| 1  | 1/2|
| B4 | 1/5| 1/2| 2  | 1  |

Calculated as described above $\lambda_{max} = 4.0192$, $w_A = [0.5872, 0.2179, 0.0722, 0.1228]$. $w_A$ is the weight of each indicator of the B layer on the A layer, that is, the total target. According to equation (1) and equation (2), $CI = 0.0064$ and $CR = 0.0071 < 0.1$ are calculated, which satisfies the consistency test of the judgment matrix. Similarly, the weights of the elements of the C layer relative to the B layer and its related elements can be calculated, as shown in Table 5.

| Motor driven | 0.5872 | Front bearing temperature | 0.3133 |
|--------------|--------|----------------------------|--------|
|              |        | Rear bearing temperature   | 0.1970 |
|              |        | Vibration intensity        | 0.0960 |
|              |        | Bearing vibration          | 0.0850 |
Coil temperature 0.0860  
Motor current 0.2227  
Load 0.1797  
Belt speed 0.1682  
Runoff 0.5576  
Tape temperature 0.0945  
Tape body 0.2179  
Load 0.1797  
Belt speed 0.1682  
Runoff 0.5576  
Tape temperature 0.0945  
Working environment 0.0722  
Ambient temperature 0.1666  
Environment humidity 0.1666  
Smoke concentration 0.3333  
Dust concentration 0.3333  
Maintenance costs 0.1228  
Failure time 0.2040  
Repair time 0.3749  
Fault frequency 0.1287  
Usage frequency 0.2924  

The calculated combined weight \( W = [0.1840, 0.1157, 0.0564, 0.0499, 0.1308, 0.0392, 0.0367, 0.1215, 0.0206, 0.0121, 0.0240, 0.0240, 0.0251, 0.0460, 0.0158, 0.0359]. \)

In this paper, the single-index subordinate results of each factor in the influence factor set \( U \) are divided into four levels: healthy, good, general, and dangerous, and form the evaluation set \( V \). According to the national standard of belt conveyor operation monitoring and the knowledge of expert experience, the membership vector of a single factor can be calculated by the calculation of the membership function of section 2.3, and the membership vector of all index factors is composed into a matrix, which is the evaluation matrix \( R \).[9]. The evaluation matrix of this example is as \( R = \begin{bmatrix} 0.125 & 0.875 & 0 & 0 & 0.2 & 0.8 & 0 & 1 & 0 & 0 & 0 & 0.333 & 0.667 & 0 & 0 & 0.1 & 0.9 & 0 & 0 & 0.49 & 0.51 & 0 & 0 & 0.3 & 0.7 & 0 & 0.3 & 0.7 & 0 & 0 & 1 & 0 & 0 & 0 & 0.867 & 0.133 & 0.0 & 0.133 & 0.867 & 0 & 0.2 & 0.8 & 0 & 0 & 1 & 0 & 0 & 0 & 0.182 & 0.818 & 0 & 0 & 0 & 0.875 & 0.125 & 0 & 0 & 0.6 & 0.4 & 0 & 0 & 0 & 0.375 & 0.625 & 0 \end{bmatrix}; \)

Finally calculate the evaluation results: \( S = W \circ R = [0.3483, 0.4377, 0.2141, 0]; \)

According to the principle of maximum membership, the grade of evaluation is good, but there is still a part of the general state, and the staff should strengthen the inspection. It has been verified that it meets the operating conditions of the site, but since the sample taken is a data sample fixed for a period of time, the evaluation result only represents the current operation.

4. Conclusion

By using the combination of AHP-FCE, the objective health status of the belt conveyor is evaluated, which eliminates the subjectivity of man-made. It provides the basis for switching redundancy and regular inspection and maintenance for the first-line operation and maintenance personnel, ensuring the safety of people and equipment in the production line.

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