Comprehensive Evaluation of Crane Hoisting Mechanism System State Based on Grey Correlation and Analytic Hierarchy Process

Yongjun Qiu[1, a], Dingdong Zou[1], Heng Yang[2] and Fanxing Meng[2]

[1]Chongqing Special Equipment Inspection and Research Institute, Chongqing 401211, China

[2]Taiyuan University of Science and Technology, Taiyuan 030024, China

[a]475652265@qq.com

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Abstract: Aiming at the problem that the comprehensive evaluation method of crane hoisting mechanism system based on AHP needs many people to participate in and the evaluation method of crane hoisting mechanism system lacks timeliness caused by complicated process, a comprehensive evaluation method of crane hoisting mechanism system based on grey correlation and AHP is proposed. Firstly, the relative weights of the bottom elements of the hierarchical model of the hoisting mechanism system with respect to the top evaluation indexes are obtained by the analytic hierarchy process (AHP). Then, the membership degree of the bottom elements with respect to the state level is obtained by the grey correlation method. Finally, the calculated values are combined to obtain the final state of the hoisting mechanism system of the crane. The method achieves the rapid evaluation of the state grade of the crane hoisting mechanism system with the participation of a small number of people, and achieves the goal of rapid evaluation.

1. Introduction

With the development of economy and the progress of science and technology, mechanical equipment is designed more large, complicated and diverse to help solve large engineering problem out of human's ability. However, the accompanied security problem is more and more prominent, casting a shadow over the society, life and production stability. When economic is developed to a certain extent, the safety problem has become a key factor that affects its development; therefore, all countries pay more attention to this problem. The method of "safety assessment" that ensure equipment safe has been gradually recognized all over the world [12] [13].

Safety evaluation often contains multi-level analysis problem, so it's need to using analytic hierarchy process. AHP, widely used in the decision and safety assessment of all kinds of complicated system [1] [3] [4] [11], is a multi-criteria decision method put forward by saaty in the 1970s. The key of Analytic hierarchy process is establishing judgment matrix, and judging the accuracy of the matrix affects the accuracy of the results of the analysis. In actual use, the method of establishing judgment matrix is widely [10], mostly obtaining from the domain expert scoring method. This method can reference to the experience of experts, making the evaluation result more professional. However, the assessment of things' state for people is usually blurry. For example, A is more important than B, but it is difficult to respect by using an accurate figure for the degree of importance. Moreover, there are various uncertainties for the evaluation system itself or the system itself is in an uncertain environment. For example, it exist randomness, fuzziness and so on. So it makes traditional hierarchy theory can't true react the system in which the situation, and it is difficult to give specific evaluation value. The fuzzy analytic hierarchy process forms by introducing the fuzzy numbers into AHP, it's widely applied because it help to solve the problem of fuzziness and randomness. For example, in literature [2], fuzzy analytic hierarchy process makes a comprehensive evaluation for system state of the portal crane slewing mechanism, in the literature [5], makes evaluation for crane machine, in literature [7], fuzzy evaluation and analytic hierarchy process passenger takes the safety evaluation method research for ropeway, literature [9] the availability of product were studied by using fuzzy AHP.

In most of the literature concerning using traditional fuzzy hierarchical make analysis of system comprehensive state, the calculation results is the membership for some certain qualitative evaluation result, which making it difficult to understand for the laymen. And literature [2] transforms the membership of multiple qualitative evaluation results into a certain value, and then judging the overall qualitative results according to the value range of the qualitative evaluation results which containing the determination value.

This paper based on the safety evaluation, Aiming at the problem that the comprehensive evaluation method of crane hoisting mechanism system based on AHP needs many people to participate in and the evaluation method of crane hoisting mechanism system lacks timeliness caused by complicated process, a comprehensive evaluation method of crane hoisting mechanism system based on grey correlation and AHP is proposed. The method achieves the rapid evaluation of the state grade of the crane hoisting mechanism system with the participation of a small number of people, and achieves the goal of rapid evaluation.

2. Comprehensive evaluation method of system state

2.1 Grey Correlation Coefficient

Based on grey system theory, comparative sequence $C_i(j)=\{C_i(1),C_i(2),\cdots,C_i(m)\}$ (therein, i=1,2,3,…n indicates number of i alternatives, $j=1,2,3,\cdots,m$ represents the number of j indicators in each scenario; $C_i(j)$ Represents the i indicator of the j plan)Relative to reference sequence $C_0(j)=\{C_0(1),C_0(2),\cdots,C_0(m)\}$ ($C_0(j)$, $j=1,2,3,\cdots,m$, Represents the index j of reference sequence).In the index C0(j) ,The correlation coefficient is shown in formula (1).

$$\xi_i(j)=\frac{\min_i\min_j\left|C_0(j)-C_i(j)\right|+\rho\max_i\max_j\left|C_0(j)-C_i(j)\right|}{\left|C_0(j)-C_i(j)\right|+\rho\max_i\max_j\left|C_0(j)-C_i(j)\right|} \tag{1}$$

In the formula, $j=1,2,\cdots m$, $\rho\in(0,+\infty)$ is Resolution coefficient. ρ is smaller, The greater the resolving power. General take $\rho\in(0,1)$, more generally take $\rho=0.5$.

2.2 Comprehensive evaluation method of system state based on Grey Relational Analysis and analytic hierarchy process

The original intention of the system state comprehensive evaluation method based on grey correlation and analytic hierarchy process is to realize the comprehensive evaluation of the system state of the equipment with the participation of only a few equipment maintenance personnel or users, so as to achieve the purpose of timely and accurate grasp of the equipment state. The steps of the method are as follows:

1) To analyze the event of target as the top event, we will refine the target layer by layer and establish an inverted tree hierarchy model.

2) Invite the user or maintainer of the state evaluation target to construct the characteristic matrix of each level according to the importance value of Table 1 by two-to-two comparison. Referring to the hierarchical model and the fuzzy evaluation of Table 2, the qualitative membership degree of the state level of the underlying index is given.

Table.1. The importance of the meaning of the scale table

Importance Index	Meaning
1	The two elements are of equal importance.
3	Compared with the two elements, the former is slightly important than the latter.
5	Compared with the two elements, the former is much important than the latter.
7	Compared with the two elements, the former is more important than the latter.
9	Compared with the two elements, the former is much more important than the latter.
2, 4, 6, 8	Represents the intermediate value of the above judgment.
Reciprocal	If the ratio of the importance of element *i* to element *j* is a_{ij}, The ratio of element *i* to element *j* is $a_{ij} = 1/a_{ij}$

3) According to the analytic hierarchy process (AHP), the maximum eigenvector of the eigenvector matrix is solved, and the consistency of the eigenvector matrix is judged by the formula (2). The weight coefficient of the bottom element relative to the top target is obtained by the hierarchical structure relationship.

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

4) The qualitative membership value of the evaluation participants was converted into quantitative membership value by grey correlation method.

According to grey correlation method, fuzzy membership reference sequence of component state grade is first established C0=(highest, highest, highest, highest) (The meaning of the expression is: the component state is superior to the state grade, the membership of good, medium and bad is highest), And the fuzzy membership reference sequence is transformed into a quantitative membership reference sequence $C0 = \{9,9,9,9\}$, Similarly, according to the corresponding values in Table2, the fuzzy membership values of the components given by the evaluators with respect to the four grades of superiority, superiority, moderation and inferiority are converted into corresponding representation values. For example, the existing state of "excellent" of bearing is superior to "general", the existing state of "good" is superior to "high", the existing state of "medium" is superior to "general", the existing state of "poor" is superior to "low", therefore, The fuzzy membership sequence is *Ci*={ general , high , general , low}, Converted to quantitative representation is $Ci = \{5,7,5,3\}$. Then, the membership degree of the component relative to the state level can be obtained and standardized by equation (1).

5) Utilizing the degree of membership and relative importance of the component state obtained by step 3) and step 4), the comprehensive evaluation matrix is established, and the final interval of the comprehensive state membership of the system is obtained.

6) By fuzzy inverse transformation, the final membership fuzzy membership level of the system is obtained.

Table.2. Fuzzy reviews and the corresponding values

Fuzzy reviews	lowest	low	general	high	highest
values	*1*	*3*	*5*	*7*	*9*

2.3 Comprehensive Evaluation of Crane Hoisting System State

Hoisting mechanism is one of the four major mechanisms of crane. Accidents caused by hoisting mechanism occupy a large part in the accidents of Crane, and hoisting mechanism is the most critical part of crane, hoisting mechanism is the main working part of crane to carry goods, so the system of crane comprehensive evaluation of state requires comprehensive evaluation of the state of lifting mechanism.

In the process of comprehensive evaluation of crane hoisting mechanism system state, it is the key to establish the hierarchical model of comprehensive evaluation of system state. Taking the comprehensive evaluation of the state of the hoisting mechanism system as the top evaluation objective, combining with the main components of the hoisting mechanism and the functions of each part, the evaluation hierarchy model is established, as shown in Figure 1. In the hierarchical model, the top level evaluation objectives can be divided into four parts: Winding parts(B1), Driving parts(B2), Deceleration device Section(B3), Brake parts(B4); Among them, the winding part(B1) can be subdivided into Reel (C1), Wire Rope (C2), Dynamic Pulley (C3), Fixed Pulley (C4), Hook (C5); Driving part (B2) can be divided into: Control Circuit (C6), Drive Motor (C7), Floating Shaft (C8), Coupling (C9); Deceleration device Section(B3) can be subdivided into: Gear (C10), Lubricant (C11), Box (C12), Bearing (C13); Brake parts(B4)can be subdivided into: Control motor and Oil circuit (C14), Brakes (C15), Brake wheel (C16).

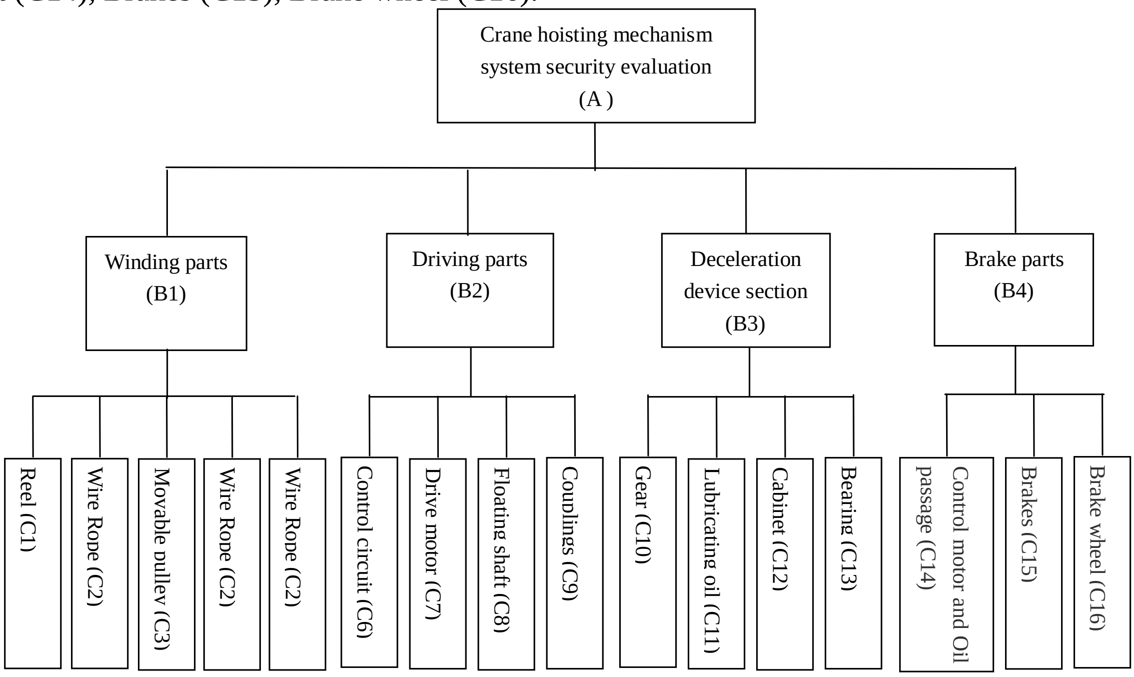

Figure 1. The model of system's safety evaluation for hoisting mechanism

3. Example

Taking a bridge crane which has been in service for five years in a machining workshop as an example, this paper evaluates the system status of its hoisting mechanism comprehensively, and illustrates the application process of the comprehensive evaluation method of the hoisting mechanism system status based on grey correlation and hierarchical analysis. In the evaluation process, one crane equipment maintenance personnel, one safety evaluation expert and one crane equipment designer are invited to participate in the comprehensive evaluation of system status.

Using the importance evaluation in Table 1, the relative importance matrix of the second level subsystem relative to the top level system and the relative importance evaluation of the third level subsystem relative to their respective corresponding subsystems are established respectively, and the evaluation is translated into corresponding scales, as shown in Table 3, Table 4, Table 5, Table 6 and Table 7.

Table.3. The evaluation matrix of the first layer evaluation index set {*B1, B2, B3, B4*} on the top-level index *A*

A	*B1*	*B2*	*B3*	*B4*
B1	1	2 2 2	2 2 1	1 2 1
B2	1/2 1/2 1/2	1	1 1 1/2	1/2 1/2 1

B3	1/2 1/2 1	1 1 2	1	1 1 1/2
B4	1 1/2 1	2 2 1	1 1 2	1

Table.4. The evaluation matrix of the second layer evaluation index set {*C1*, *C2*, *C3*, *C4*, *C5*} on the top-level index *B1*

B1	*C1*	*C2*	*C3*	*C4*	*C5*
C1	1	1/3 1/3 1/2	1/3 1/2 1/2	1 1 1/2	1 1/2 1/2
C2	3 3 2	1	1 2 1	3 2 2	1 2 2
C3	3 2 2	1 1/2 1	1	1 2 2	1 2 1
C4	1 1 2	1/3 1/2 1/2	1 1/2 1/2	1	1 1/2 1
C5	1 2 2	1 1/2 1/2	1 1/2 1	1 2 1	1

Table.5. The evaluation matrix of the second layer evaluation index set {*C6*, *C7*, *C8*, *C9*} on the top-level index B2

B2	*C6*	*C7*	*C8*	*C9*
C6	1	1 1/2 1	2 2 1	2 1 1
C7	1 2 1	1	1 2 2	2 1 1
C8	1/2 1/2 1	1 1/2 1/2	1	1/2 1 1
C9	1/2 1 1	1/2 1 1	2 1 1	1

Table.6. The evaluation matrix of the second layer evaluation index set {*C10*, *C11*, *C12*, *C13*} on the top-level index *B3*

B3	*C10*	*C11*	*C12*	*C13*
C10	1	1 2 2	2 2 2	2 1 1
C11	1/2 1/2 1	1	2 1 1	1/2 1 1
C12	1/2	1/2	1	1/2

	1/2 1/2	1 1		1/2 1
C13	1/2 1 1	2 1 1	2 2 1	1

Table.7. The fuzzy evaluation matrix of the second layer evaluation index set {*C14*, *C15*, *C16*} on the top-level index *B4*.

B4	*C14*	*C15*	*C16*
C14	1	1 1/2 1	2 1 1
C15	1 2 1	1	2 2 2
C16	1/2 1 1	1/2 1/2 1/2	1

Taking the first evaluation index set {B1, B2, B3, B4} as an example, the calculation process of the standard weight ratio of the comparison matrix of the upper index A is illustrated:

Integrate the comparison matrix of the first evaluation index set {B1, B2, B3, B4} with respect to the top indicator A, as shown in Table 8.

Table.8. The Integrated evaluation matrix of the first layer evaluation index set {*B1, B2, B3, B4*} relative to the top-level index *A*.

A	*B1*	*B2*	*B3*	*B4*
B1	1	2	1.667	1.333
B2	0.5	1	0.833	0.667
B3	0.667	1.333	1	0.833
B4	0.833	1.667	1.333	1

Using the comparison matrix, the maximum values and corresponding diagnostic vectors are obtained:

$\lambda_{\max} = 4.1352$

Feature vector: $U = \left(-0.6590, -0.3295, -0.4209, -0.5292\right)$

The consistency of the comparison matrix is judged:

Index of inconsistency degree: $C.I. = \dfrac{4.1352-4}{4-1} = 0.0451$

Random consensus ratio: $CR = \dfrac{C.I}{RI} = \dfrac{0.0451}{0.9} = 0.0501 < 0.1$

Therefore, the comparison matrix satisfies the consistency requirement.

The normalization of eigenvectors is used to get the weights of each index relative to the upper index:

$w(B1, B2, B3, B4) = \left(0.3399, 0.17, 0.2171, 0.273\right)$

According to the above method, the weight ratio of second level B1~C1, C2, C3, C4, C5; B2~C6, C7, C8, C9; B3~C10, C11, C12, C13; B1~C14, C15, C16 evaluation index is calculated.

$w(C1, C2, C3, C4, C5) = \left(0.1139, 0.3074, 0.2435, 0.1457, 0.1895\right)$

$w(C6, C7, C8, C9) = \left(0.2753, 0.3097, 0.1838, 0.2312\right)$

$w(C10, C11, C12, C13) = \left(0.3399, 0.2171, 0.1700, 0.2730\right)$

$w(C14, C15, C16) = \left(0.3268, 0.437, 0.2362\right)$

After obtaining the relative importance of the components relative to the upper index through the characteristic matrix, three participants were asked to make fuzzy comments on the possibility that the components of the crane hoisting mechanism have excellent, good, medium and poor state relative to the existing state, for example, the rollers of the winding part are in the present state. The possibility of "excellent" state level is high, the possibility of "good" state level is "general", the possibility of "middle" state level is "low" and the possibility of "poor" state level is "lowest". After evaluating all the components, three participants can get the possibility of the state level of the components. The rating scale is shown in table 9.

Table.9. The state of Component of the possible level evaluation form

Parts	Evaluator 1				Evaluator 2				Evaluator 3			
	excellent	good	medium	poor	excellent	good	medium	poor	excellent	good	medium	poor
C1	high	general	low	lowest	highest	low	lowest	lowest	general	high	low	lowest
C2	low	low	highest	low	lowest	low	low	highest	low	general	high	low
C3	high	general	low	lowest	high	general	general	lowest	high	general	low	lowest
C4	highest	general	lowest	lowest	high	general	low	lowest	general	highest	lowest	lowest
C5	highest	general	low	lowest	high	high	low	lowest	highest	general	lowest	lowest
C6	highest	general	lowest	lowest	high	general	low	lowest	highest	general	lowest	lowest
C7	general	general	high	low	general	high	low	low	general	high	general	low
C8	highest	lowest	lowest	lowest	highest	general	lowest	lowest	general	highest	general	low
C9	highest	low	lowest	lowest	high	low	low	lowest	highest	low	lowest	lowest
C10	general	general	high	low	low	general	high	general	general	low	high	general
C11	high	high	general	lowest	highest	low	low	low	general	high	low	low
C12	highest	low	lowest	lowest	highest	lowest	general	lowest	highest	lowest	lowest	lowest
C13	lowest	low	highest	low	low	general	high	general	lowest	general	high	low
C14	highest	general	lowest	lowest	high	general	low	lowest	highest	general	low	lowest
C15	low	low	high	low	lowest	low	highest	general	low	general	highest	lowest
C16	low	general	high	low	low	high	high	low	low	low	highest	general

Through the qualitative description of the possibility of the existing state grades of the components of the crane hoisting mechanism system by the three evaluators in Table 9. The membership values of the existing state grades of the components can be obtained by the grey relational method.

Selecting numerical expression of reference sequence: $C0 = \left\{9, 9, 9, 9\right\}$

Conversion of evaluation indicators and formation of comparative sequences:

$C1 = \left\{7, 5, 3, 1\right\}$, $C2 = \left\{7, 5, 5, 1\right\}$, $C2 = \left\{7, 5, 3, 1\right\}$

Dimensionless processing of reference sequences and comparison sequences is carried out:

$C0 = \left\{1.2, 1.5, 1.8, 3\right\}$, $C1 = \left\{0.9333, 0.8333, 0.6, 0.3333\right\}$, $C2 = \left\{0.9333, 0.8333, 1, 0.3333\right\}$

$C3 = \left\{0.9333, 0.8333, 0.6, 0.3333\right\}$

Using the formula (1), the correlation coefficient of the comparison sequence relative to the reference sequence is obtained.

$\xi_1 = \left\{1, 0.8, 0.6316, 0.4\right\}$, $\xi_2 = \left\{1, 0.8, 0.75, 0.4\right\}$, $\xi_3 = \left\{1, 0.8, 0.6316, 0.4\right\}$

Taking the ξ_1 , ξ_2 , ξ_3 average:

$\xi_j = \left\{1, 0.8, 0.6711, 0.4\right\}$

By standardizing the average correlation coefficient, the membership degree of the existing state of the dynamic pulley relative to the state grade (excellent, good, medium, poor) is obtained.

$w_{C3} = \left(0.3483, 0.2786, 0.2337, 0.1393\right)$

By using the above method, the membership degree of other components relative to the state grade can be obtained.

$w_{C1} = (0.3678, 0.2942, 0.1936, 0.1444)$, $w_{C2} = (0.1505, 0.2008, 0.3511, 0.2976)$

$w_{C4} = (0.3577, 0.337, 0.1649, 0.1404)$, $w_{C5} = (0.3866, 0.2958, 0.1819, 0.1356)$

$w_{C6} = (0.4057, 0.2847, 0.1672, 0.1424)$, $w_{C7} = (0.2498, 0.3228, 0.2609, 0.1665)$

$w_{C8} = (0.3788, 0.2941, 0.1771, 0.1499)$, $w_{C9} = (0.4368, 0.2299, 0.1800, 0.1533)$

$w_{C10} = (0.2131, 0.2131, 0.3607, 0.2131)$ $w_{C11} = (0.3444, 0.2891, 0.2066, 0.1599)$

$w_{C12} = (0.4692, 0.1668, 0.1972, 0.1668)$ $w_{C13} = (0.1523, 0.2475, 0.377, 0.2232)$

$w_{C14} = (0.3963, 0.2781, 0.1865, 0.1391)$ $w_{C15} = (0.163, 0.2134, 0.4324, 0.1911)$

$w_{C16} = (0.1615, 0.2531, 0.3965, 0.1888)$

Thus, a comprehensive evaluation table 10 was obtained.

According to the data in table 10, the total evaluation matrix is obtained:

$$R = \begin{bmatrix} M1 \\ M2 \\ M3 \\ M4 \end{bmatrix} = \begin{bmatrix} 0.2893 & 0.2682 & 0.2454 & 0.1880 \\ 0.3597 & 0.2856 & 0.2010 & 0.1538 \\ 0.2685 & 0.2311 & 0.3039 & 0.1964 \\ 0.2389 & 0.2439 & 0.3435 & 0.1736 \end{bmatrix}$$

Table.10. The table of system's safety comprehensive assessment for hoisting mechanism of crane

Evaluation goal	First level evaluation index	The relative weight of the first level evaluation target	Second level evaluation index	The relative weight of the second level evaluation target	Ranking of overall importance of two level evaluation indicators		excellent	good	medium	poor
A	*B1*	0.3399	C1	0.1139	0.0387	*S1*	0.3678	0.2942	0.1936	0.1444
			C2	0.3074	0.1045		0.1505	0.2008	0.3511	0.2976
			C3	0.2435	0.0828		0.3483	0.2786	0.2337	0.1393
			C4	0.1457	0.0501		0.3577	0.3370	0.1649	0.1404
			C5	0.1895	0.0644		0.3866	0.2958	0.1819	0.1356
	B2	0.1700	C6	0.2753	0.0468	*S2*	0.4057	0.2847	0.1672	0.1424
			C7	0.3097	0.0526		0.2498	0.3228	0.2609	0.1665
			C8	0.1838	0.0312		0.3788	0.2941	0.1771	0.1499
			C9	0.2312	0.0393		0.4368	0.2299	0.1800	0.1533
	B3	0.2171	C10	0.3399	0.0738	*S3*	0.2131	0.2131	0.3607	0.2131
			C11	0.2171	0.0471		0.3444	0.2891	0.2066	0.1599
			C12	0.1700	0.0369		0.4692	0.1668	0.1972	0.1668
			C13	0.2730	0.0593		0.1523	0.2475	0.3770	0.2232
	B4	0.2730	C14	0.3268	0.0892	*S4*	0.3963	0.2781	0.1865	0.1391
			C15	0.4370	0.1193		0.1630	0.2134	0.4324	0.1911
			C16	0.2362	0.0645		0.1615	0.2531	0.3965	0.1888

The final evaluation of the system is obtained.

$$M = W \times R$$

$$= \left(0.3399, 0.17, 0.2171, 0.273\right) \times \begin{bmatrix} 0.2893 & 0.2682 & 0.2454 & 0.1880 \\ 0.3597 & 0.2856 & 0.2010 & 0.1538 \\ 0.2685 & 0.2311 & 0.3039 & 0.1964 \\ 0.2389 & 0.2439 & 0.3435 & 0.1736 \end{bmatrix}$$

$$= \left(0.2830, 0.2565, 0.2773, 0.1831\right)$$

Select the interval of the state grade to be (excellent, good, medium, pool)=([0.8,1], [0.6,0.8], [0.4,0.6], [0.2, 0.4]), The final system's comprehensive state score is as follows:

$$f = \sum_{i=1}^{n} t_i f_i$$

$$= 0.283 \times \left[0.8,1\right] + 0.2565 \times \left[0.6, 0.8\right] + 0.2773 \times \left[0.4, 0.6\right] + 0.1831 \times \left[0.2, 0.4\right]$$

$$= \left[0.5278, 0.7278\right]$$

Therefore, the fuzzy state of the system tends to be "good".

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References are cited in the text just by square brackets [1]. Two or more references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under heading references, see our example below.

4. Conclusion

In view of the difficulty in calculating the weighting coefficients in the comprehensive evaluation of crane hoisting mechanism system, a comprehensive evaluation method of crane hoisting mechanism system based on grey correlation and analytic hierarchy process (AHP) is proposed in this paper.

Through the analysis of an example, the calculation process of this method in the comprehensive evaluation of crane hoisting mechanism state is illustrated. The results show that this method has better operability and practical consistency for the complex, multi-level and fuzzy information problems, and solves the problem of difficult calculation of traditional method weight.

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