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Application of the analytic hierarchy process-fuzzy comprehensive evaluation method to assess the quality of electrophoresis on heavy-duty vehicle frames

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ABSTRACT

The evaluation methods used to examine the quality of electrophoresis painting applied to heavy-duty vehicle frames in the automotive industry are not comprehensive. Therefore, this investigation presents such a method based on the present manufacturing situation concerning the electrophoresis process for frames, using an evaluation index system designed for frame electrophoresis quality management. Based on the previous literature, the analytic hierarchy processand the fuzzy evaluation method are employed in this study for the evaluation. Per the principle of maximum membership, we assessed the production quality of heavy-duty vehicle frames. The presentation quality was deemed "average," while the paint film quality, corrosion resistance was good, and comprehensive evaluation grade were found to be "good". Together, these results contribute to the state of the art by facilitating an accurate evaluation of the quality of vehicle frame electrophoresis, improving the electrophoresis process for heavy-duty vehicle frames.

Keywords: heavy-duty vehicle frame electrophoresis, analytic hierarchy process, fuzzy comprehensive evaluation, quality assessment.

INTRODUCTION

With the rapid development of the global economy and automobile technology, the manufacturing and sales of heavy-duty vehicles are increasing, leading to higher demands for components and promoting the development and application of new technology, equipment, and production processes. As the core component of heavy-duty vehicles, the frame not only connects to the body, engine, driving system, transmission system, and other key assembly parts but also bears the impacts and vibrations associated with loads, dead weight, and various complex working conditions [1]. The electrophoretic quality of the frames is directly related to the reliability and stability of heavy-duty vehicles. The electrophoresis process for heavy-duty vehicle frames is not only complex, but also requires high standards. The process flow of heavy-duty vehicle frames electrophoresis are as follows: pretreatment → mounting → degreasing → water washing → surface adjustment → phosphating → water washing → circulating deionized water immersion → electrophoresis → ultrafiltration water spraying → deionized water spraying → electrophoretic paint drying → strong cooling → offline – inspection [2].

With the continuous improvements in vehicle carrying capacity, requirements regarding the quality of vehicle frame electrophoresis are increasing, representing not only the surface quality of the frame but also its performance and stability. At present, there is limited research and a single method for evaluating the electrophoretic quality of heavy-duty vehicle frames. Zhu et al. proposed a frame electrophoresis quality evaluation based on the fuzzy comprehensive evaluation method; however, the indicators are too simple and the evaluation results are not accurate enough

[3]. Yang al. proposed an evaluation of the quality of the electrophoretic paint film on vehicle frames, but the indicator system is not accurate enough and only evaluates the weight of each indicator[4]. Zheng. developed a technical index framework for evaluating the quality of frame electrophoresis, but did not analyze it in conjunction with various indicators in the field of frame electrophoresis quality management[5]. Dai et al. only studied the effect of production pace on the quality of frame electrophoresis and did not make corresponding quality evaluations [6]. Zhu et al. studied the influence of factors such as PH value, conductivity, temperature, and voltage on the quality of frame electrophoresis, and obtained the relationship between each factor and the quality of frame electrophoresis; And qualitatively evaluate the appearance quality and adhesion of the frame electrophoresis [1]. The electrophoretic quality of frames is characterized by multiple factors, including complexity and fuzziness, making it difficult to conduct a scientific and objective evaluation through qualitative analysis. Therefore, it is crucial to select a reasonable evaluation method to improve the quality of frame electrophoresis. A comprehensive evaluation of the quality of frame electrophoresis is beneficial for discovering weak links in the management process, thus improving the performance and quality of the frame.

In order to improve the reliability and accuracy of electrophoretic quality evaluation of heavy-duty vehicle frames. In this study, we constructed an analytical frames based on actual production conditions. Using the analytic hierarchy process to determine the weight evaluation indicators for frames electrophoresis, and combining with the fuzzy comprehensive evaluation method to comprehensively evaluate the quality of frames electrophoresis, in order to identify weak links in the production management process of framework electrophoresis quality and make improvements.

MATERIALS AND METHODS

Evaluation system for quality heavy-duty vehicle frame electrophoresis

When evaluating the quality of vehicle frame electrophoresis, the selected evaluation indices must adhere to the principles of systematization and hierarchy. Thus, in this study, we propose a hierarchical model based on the previous literature and determine the significance of the relationship based on expert opinions. This hierarchical model includes three layers – target, criterion, and indicator – with the criterion layer comprising three criterion sublayers and the indicator layer comprising nine index layers. The specific index evaluation system is detailed in Table 1.

Determination of evaluation system indicators

Process for determining indicator weights

Determining the weight of each index level is the first step in a comprehensive evaluation of the quality of electrophoresis conducted on heavy-duty vehicle frames. Commonly used methods to determine index weights include principal component analysis, hierarchical analysis, the Delphi method, and the maximum entropy technical method [7–10]. To improve the evaluation accuracy, we employ the hierarchical analysis method to determine the weights of all indicator levels. The specific process is as follows:

Table 1. Quality evaluation system for heavy-duty vehicle frame electrophoresis

Target layer	Criterion layer	Indicator layer
Frame electrophoresis quality evaluation system	Presentation quality B_1	Chromatic aberration B_{11}
		Layer defect B_{12}
		Flow mark B_{13}
	Paint film quality B_2	Paint film thickness B_{21}
		Paint film adhesion B_{22}
		Paint film hardness B_{23}
	Corrosion resistance B_3	Resistance to alkali B_{31}
		Salt mist corrosion B_{32}
		Resistance to oil B_{33}

1. Build a hierarchy structure. The target layer refers to the quality of electrophoresis conducted on a heavy-duty vehicle frame, and the criterion and indicator layers are established subsequently according to the evaluation system's framework.
2. Determine the judgment matrix. Experts are invited to assign values to indicators at each level, and the comparison scale table determined by Saaty (Table 2) is used as a reference to perform a pairwise comparison of the various indicators of each layer and construct a judgment matrix.

Two element indices xm and xn are selected from the same index level, and amn represents the comparison of the influence of the indices xm and xn on vehicle frame electrophoresis quality. All of the comparison results at the same level are represented by a matrix known as a judgment matrix. Hierarchical consistency testing. The maximum eigenvalue λmax is calculated according to the judgment matrix and the corresponding eigenvector W. The consistency check index (CI) used to calculate the judgment matrix is as calculated follows [12]:

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

The consistency ratio (CR) of the judgment matrix calculated from the average random consistency index table is determined as follows [13]:

$$CR = \frac{CI}{RI} \quad (2)$$

where: *RI* is the randomness index. The average *RI* is detailed in Table 3.

Generally, if CR < 0.1, the judgment matrix is considered to have passed the consistency test; otherwise, it lacks satisfactory consistency.

Determination of index weights for the evaluation system

After the index weights for the frame electrophoresis evaluation system are determined, the weights of each element in the criterion layer are calculated. In this study, more than 15 experts from relevant fields were invited to evaluate and score the average values. Based on their importance (listed by significance in the table), the three influencing factors of presentation quality, paint film quality, and corrosion resistance underwent a pairwise comparison to obtain the evaluation matrix shown in Table 4. The evaluation matrix R can be expressed as follows:

$$\boldsymbol{R} = \left(r_{ij}\right)_{3\times3} = \begin{pmatrix} 1 & 0.6 & 0.74 \\ 1.67 & 1 & 0.65 \\ 1.35 & 1.54 & 1 \end{pmatrix} \quad (3)$$

We calculate the weights W and λmax for each factor in the criterion layer are shown as follows:

$$\boldsymbol{W} = \{w_1, w_2, w_3\} = \{0.245, 0.3476, 0.4074\} \quad (4)$$

$$\boldsymbol{A} = \boldsymbol{R} \times \boldsymbol{W} = \begin{pmatrix} 0.7550 \\ 1.0216 \\ 1.2734 \end{pmatrix} \quad (5)$$

$$\lambda_{\max} = \frac{1}{3}\left(\frac{0.755}{0.245} + \frac{1.0216}{0.3476} + \frac{1.2734}{0.4047}\right) = 3.0488 \quad (6)$$

Table 2. Evaluation system for the quality of electrophoresis conducted on a heavy-duty vehicle frame [11]

Scale	Meaning
1	The m factor is equally important as the n factor
3	The m factor is slightly more important than the n factor
5	The m factor is more important than the n factor
7	The m factor is strongly more important than the n factor
3	The m factor is extremely more important than the n factor
2, 4, 6, 8	Intermediate degree between two adjacent degrees
Reciprocal	Comparison of the importance of n factors over m factors

Table 3. Average RI [14]

Matrix order	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 4. Evaluation matrix of various factors in the criterion layer

B	B_1	B_2	B_3
B_1	1	0.6	0.74
B_2	1.67	1	0.65
B_3	1.35	1.54	1

For the consistency test, given that n = 3, the value of the RI is 0.58, and the CI can be calculated: As CI/RI = 0.0421 < 0.1, the consistency test passed. The evaluation process of the criterion layer is summarized in Table 5. Referring to the above calculation method, the indicator layer and test results were obtained, as shown in Tables 6–8. Based on the weights and consistency test results for the layers, the weights of various indicators for the quality of electrophoresis for a heavy-duty frame were obtained, as shown in Table 9. Table 9 shows that, for the criterion layer, electrophoresis quality is ranked in the following order: corrosion resistance, paint film quality, and presentation quality. The evaluation results show that the corrosion resistance with the highest weight is a key indicator, and thus, reasonable processes should be adopted to improve corrosion resistance during the manufacturing process. Considering the specific aspects of quality management (i.e., the indicator layer), the first three indicators that need to be controlled when evaluating the quality of electrophoresis conducted on heavy-duty vehicle frames are alkali resistance, paint film adhesion, and layer defects, followed by flow marks, oil

Table 5. Criterion layer judgment matrix, weights, and consistency testing

B_I	B_1	B_2	B_3	W
B_1	1	0.6	0.74	0.245
B_2	1.67	1	0.65	0.3476
B_3	1.35	1.54	1	0.4074
Consistency check	λmax = 3.0488; CI/RI < 0.1 through inspection			

Table 6. Presentation quality in the judgment matrix, weights, and consistency testing

B_1	B_{11}	B_{12}	B_{13}	W
B_{11}	1	0.33	3	0.3105
B_{12}	3	1	4	0.5759
B_{13}	0.33	0.25	1	0.1136
Consistency check	λmax = 3.1037; CI/RI < 0.1 through inspection			

Table 7. Paint film quality in the judgment matrix, weights, and consistency testing

B_2	B_{21}	B_{22}	B_{23}	W
B_{21}	1	0.25	0.59	0.1587
B_{22}	4	1	1.27	0.5409
B_{23}	1.69	0.79	1	0.3004
Consistency check	λmax = 3.0537; CI/RI < 0.1 through inspection			

Table 8. Corrosion resistance in the judgment matrix, weights, and consistency testing

B_3	B_{31}	B_{32}	B_{33}	W
B_{31}	1	3.87	4.95	0.6289
B_{32}	0.26	1	3	0.2727
B_{33}	0.2	0.33	1	0.0984
Consistency check	λmax = 3.1154; CI/CR < 0.1 through inspection			

Table 9. Weights of indicators of electrophoresis quality for heavy-duty vehicle frames in the electrophoresis quality evaluation system

Target layer	Criterion layer	Weight	Indicator layer	Weight	Relative to the target layer weight	Rank
Frame electrophoresis quality evaluation system	Presentation quality B_1	0.245	Chromatic aberration B_{11}	0.3105	0.0761	6
			Layer defect B_{12}	0.5759	0.1411	3
			Flow mark B_{13}	0.1136	0.0278	9
	Paint film quality B_2	0.3476	Paint film thickness B_{21}	0.1587	0.0551	7
			Paint film adhesion B_{22}	0.5409	0.1880	2
			Paint film hardness B_{23}	0.3004	0.1043	5
	Corrosion resistance B_3	0.4074	Resistance to alkali B_{31}	0.6289	0.2562	1
			Salt mist corrosion B_{32}	0.2727	0.1109	4
			Resistance to oil B_{33}	0.0983	0.0405	8

resistance, and paint film thickness, which are relatively low. These results indicate various measures are necessary to improve the quality of electrophoresis conducted on heavy-duty vehicle frames.

Fuzzy comprehensive evaluation of vehicle frame electrophoresis quality

Fuzzy comprehensive evaluation process

The fuzzy comprehensive evaluation method includes the following three steps [15, 16]:

1. Establish the factor set. Through the hierarchical structure of the evaluation index system, the corresponding factor set B for the fuzzy comprehensive evaluation method can be determined. The first-level evaluation element sets are:

- $B = (B_1, B_2, B_3)$ = (presentation quality, paint film quality, corrosion resistance).

The second-level evaluation element sets are

- B1 = (B_{11}, B_{12}, B_{13}) = (chromatic aberration, layer defect, flow mark);
- B2 = (B_{21}, B_{22}, B_{23}) = (paint film thickness, paint film adhesion, paint film hardness);
- B3 = (B_{31}, B_{32}, B_{33}) = (resistance to alkali, salt mist corrosion, resistance to oil).

2. Establish the evaluation set. According to the actual process of electrophoresis quality management for a heavy-duty vehicle frame, the evaluation set V for the current electrophoresis quality management status is determined to be V_1, V_2, V_3, V_4, and V_5, corresponding to best, good, average, poor, and extremely poor, respectively, equal to 5, 4, 3, 2, and 1, respectively.

3. Establish the weight set of each factor. According to the calculation, the weight set of each factor can be obtained as follows:

- W = (0.245, 0.3476, 0.4074);
- W_1 = (0.3105, 0.5759, 0.1136);
- W_2 = (0.1587, 0.5409, 0.3004);
- W_3 = (0.6289, 0.2727, 0.0983).

Implementation of the fuzzy comprehensive evaluation

Data from the results of the evaluation conducted on the frame electrophoresis quality indicators, as derived from the expert opinions, were organized, yielding the quality indicators listed in Table 10. From Table 10, a fuzzy evaluation matrix for various indicators of the quality of electrophoresis conducted on a heavy-duty vehicle frame was obtained as follows:

$$\boldsymbol{R}_1 = \begin{pmatrix} 0.3 & 0.4 & 0.3 & 0 & 0 \\ 0 & 0.2 & 0.4 & 0.3 & 0.1 \\ 0 & 0.2 & 0.5 & 0.2 & 0.1 \end{pmatrix} \tag{8}$$

$$\boldsymbol{R}_2 = \begin{pmatrix} 0.2 & 0.5 & 0.3 & 0 & 0 \\ 0 & 0.4 & 0.3 & 0.2 & 0.1 \\ 0.1 & 0.3 & 0.3 & 0.2 & 0.1 \end{pmatrix} \tag{9}$$

$$\boldsymbol{R}_3 = \begin{pmatrix} 0.1 & 0.5 & 0.3 & 0 & 0 \\ 0.2 & 0.3 & 0.3 & 0.2 & 0 \\ 0 & 0.2 & 0.3 & 0.4 & 0.1 \end{pmatrix} \tag{10}$$

Next, we determined the fuzzy comprehensive evaluation vectors DI, corresponding to each indicator factor B_I. The calculation results yield the following quality management evaluation matrix R for electrophoresis conducted on a heavy-duty vehicle

Table 10. Expert judgment results of electrophoresis quality indicators

Criterion layer	Indicator layer	Weight	Best	Good	Average	Poor	Extremely poor
Presentation quality B_1	Chromatic aberration B_{11}	0.3105	0.3	0.4	0.3	0	0
	Layer defect B_{12}	0.5759	0	0.2	0.4	0.3	0.1
	Flow mark B_{13}	0.1136	0	0.2	0.5	0.2	0.1
Paint film quality B_2	Paint film thickness B_{21}	0.1587	0.2	0.5	0.3	0	0
	Paint film adhesion B_{22}	0.5409	0	0.4	0.3	0.2	0.1
	Paint film hardness B_{23}	0.3004	0.1	0.3	0.3	0.2	0.1
Corrosion resistance B_3	Resistance to alkali B_{31}	0.6289	0.1	0.5	0.3	0	0
	Salt mist corrosion B_{32}	0.2727	0.2	0.4	0.2	0.2	0
	Resistance to oil B_{33}	0.0983	0	0.2	0.3	0.4	0.1

frame (Equation 11–14). The results for the comprehensive evaluation of the quality of electrophoresis conducted on heavy-duty vehicle frames were then obtained (Equation 15).

RESULTS

The above evaluation results of the quality of heavy-duty vehicle frame electrophoresis are summarized in Table 11. According to the principle of maximum membership [17–19], the following conclusions can be drawn:

- From the perspective of presentation quality, Dmax = 0.3803 indicates average electrophoresis quality; thus, the appearance quality of a treated heavy-duty vehicle frame is generally acceptable.
- From the standpoint of paint film quality, Dmax = 0.3858 indicates high-quality electrophoresis; thus, the paint film quality of a certain type of heavy-duty vehicle frame after electrophoresis is good.

$$\boldsymbol{D}_1 = \boldsymbol{W}_1 \times \boldsymbol{R}_1 = \begin{pmatrix}0.3105 & 0.5759 & 0.1136\end{pmatrix} \times \begin{pmatrix} 0.3 & 0.4 & 0.3 & 0 & 0 \\ 0 & 0.2 & 0.4 & 0.3 & 0.1 \\ 0 & 0.2 & 0.5 & 0.2 & 0.1 \end{pmatrix} = (0.0931, 0.2621, 0.3803, 0.1955, 0.0690) \tag{11}$$

$$\boldsymbol{D}_2 = \boldsymbol{W}_2 \times \boldsymbol{R}_2 = \begin{pmatrix}0.1587 & 0.5409 & 0.3004\end{pmatrix} \times \begin{pmatrix} 0.2 & 0.5 & 0.3 & 0 & 0 \\ 0 & 0.4 & 0.3 & 0.2 & 0.1 \\ 0.1 & 0.3 & 0.3 & 0.2 & 0.1 \end{pmatrix} = (0.0618, 0.3858, 0.3000, 0.1683, 0.0841) \tag{12}$$

$$\boldsymbol{D}_3 = \boldsymbol{W}_3 \times \boldsymbol{R}_3 = \begin{pmatrix}0.6289 & 0.2727 & 0.0983\end{pmatrix} \times \begin{pmatrix} 0.1 & 0.5 & 0.3 & 0 & 0 \\ 0.2 & 0.4 & 0.2 & 0.2 & 0 \\ 0 & 0.2 & 0.3 & 0.4 & 0.1 \end{pmatrix} = (0.1774, 0.4432, 0.2727, 0.0939, 0.0098) \tag{13}$$

$$R = \begin{pmatrix} 0.0931 & 0.2621 & 0.3803 & 0.1955 & 0.0690 \\ 0.0618 & 0.3858 & 0.3000 & 0.1683 & 0.0841 \\ 0.1774 & 0.4432 & 0.2727 & 0.0939 & 0.0098 \end{pmatrix} \tag{14}$$

$$\boldsymbol{D} = \boldsymbol{W} \times \boldsymbol{R} = (0.245, 0.3476, 0.4074) \times \begin{pmatrix} 0.0931 & 0.2621 & 0.3803 & 0.1955 & 0.0690 \\ 0.0618 & 0.3858 & 0.3000 & 0.1683 & 0.0841 \\ 0.1774 & 0.4432 & 0.2727 & 0.0939 & 0.0098 \end{pmatrix} = (0.1168, 0.3789, 0.3087, 0.1448, 0.0508) \tag{15}$$

Table 11. Evaluation indicators for the current status of quality of electrophoresis conducted on a heavy-duty vehicle frame

Criterion layer	Best	Good	Average	Poor	Extremely poor
Presentation quality	0.0931	0.2621	**0.3803**	0.1955	0.0690
Paint film quality	0.0618	**0.3858**	0.3000	0.1683	0.0841
Corrosion resistance	0.1774	**0.4432**	0.2727	0.0939	0.0098
Comprehensive evaluation	0.1168	**0.3789**	0.3087	0.1448	0.0508

- From the perspective of corrosion resistance, Dmax = 0.4432 indicates high-quality electrophoresis; thus, the corrosion resistance of a certain type of heavy-duty vehicle frame after electrophoresis is good.

Overall, the electrophoresis treatment on a heavy-duty vehicle frame shows good performance (Dmax = 0.3789). Frame pre-treatment, electrophoresis voltage, electrophoresis tank liquid, drying temperature, cooling time, and other factors also critically impact the quality of the frame electrophoresis process. During manufacturing processes, measures such as improving the intelligence of electrophoresis production lines, increasing the number of quality control alarms on electrophoresis production lines, increasing the awareness of on-site manufacturing personnel, strictly controlling process parameters, and regularly maintaining key equipment can be taken to improve the quality of electrophoresis process on heavy-duty vehicle frames.

CONCLUSIONS

Using the layer analysis method to construct a quality management system and analyze the electrophoresis process conducted on heavy-duty vehicle frames showed that corrosion resistance was the most important influencing factor among the three criterion layers, while presentation quality had the least impact on the electrophoresis quality. The comprehensive weights of alkali resistance (0.2562), paint film adhesion (0.188), and layer defects (0.1411) in the indicator layer were relatively high, meaning that these factors should be carefully controlled during manufacturing processes.

The fuzzy evaluation method was used to comprehensively evaluate the quality of electrophoresis conducted on heavy-duty vehicle frames, showing that the quality of electrophoresis treatment on a certain type of heavy-duty vehicle frame was highly ranked (Dmax = 0.3789).

In this study, a quality evaluation system was proposed to evaluate the electrophoresis process conducted on heavy-duty vehicle frames. Based on expert scoring, hierarchical analysis and the fuzzy comprehensive evaluation method were utilized to comprehensively evaluate and optimize the quality of electrophoresis applied to heavy-duty vehicle frames. These approaches not only combined qualitative and quantitative evaluation methods effectively but also solved problems relating to the fuzziness and uncertainty of electrophoresis quality evaluation processes. Moreover, the evaluation results are vector sets rich in information, overcoming the single-result problem of traditional evaluation methods. However, the fuzzy comprehensive evaluation method also results in subjectivity when setting weights, which may be influenced by expert input. Therefore, this method requires large amounts of data and information.

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REFERENCES

1. Zhu, Z.C.; Guo, R.F.; Nie, G.Z. Experimental study on heavy truck frame electrophoresis process. Development & Innovation of Machinery & Electrical Products 2017, 30, 17–19.
2. Xiang, L.Q.; Wu, J.X. Reason analysis and solution for poor adhesion of electrophoretic paint film on light truck frame. Electroplating & Finishing 2022, 30, 399–402. https://doi.org/10.19289/j.1004-227x.2022.06.005

3. Zhu, Z.C.; Wei, J.C.; Guo, R.F. Fuzzy evaluation of electrophoretic quality of heavy-duty vehicle frames. Electroplating & Finishing 2018, 37, 80–82. https://doi.org/10.19289/j.1004-227x.2018.02.008
4. Yang, T.Y.; Wang, H.T.; Chen, Z.Z. Analysis and solution of quality issues in electrophoretic coatings. Electroplating & Finishing 2020, 39, 1563–1568. https://doi.org/10.19289/j.1004-227x.2020.22.009
5. Zheng, N. Brief analysis of quality control in pretreatment and e-coating processes. Modern Paint and Finishing 2019, 22, 45–48.
6. Dai, S.H.; Wang, P.; Wang, L. Effect of takt improvement on auto body electrophoresis quality & improvement. Automobile Technology & Material 2020, 11, 45–48. https://doi.org/10.19710/J.cnki.1003-8817.20200044
7. Valerio A, P.S.; Luiz F, A.M.G. Consistency improvement in the analytic hierarchy process. Mathematics 2024, 12, 828. https://doi.org/10.3390/math12060828
8. Zhu, Q.X.; Luo, P.P.; Wang, P.P. Operation process identification for intelligent drill rig base on analytic hierarchy process. Meitiandizhi Yu Kantan/Coal Geology and Exploration 2024, 52, 184–190. https://doi.org/10.12363/issn.1001-1986.23.06.0327
9. Xue, B.; Lu, F.; Guo, J. Research on energy efficiency evaluation model of substation building based on AHP and fuzzy comprehensive theory. Sustainability 2023, 15, 14493. https://doi.org/10.3390/su151914493
10. Saucedo-Martinez J, A.; Salais-Fierro T, E.; Rodriguez-Aguilar, R. Selecting the distribution system using AHP and Fuzzy AHP methods. Mobile networks & applications 2024, 1, 235–242. https://doi.org/10.1007/s11036-023-02290-9
11. Saaty T.L.; Vargas L.G. Inconsistency and rank preservation. Journal of Mathematical Psychology 1984, 28, 205–214. https://doi.org/10.1016/0022-2496(84)90027-0
12. Saaty T.L. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 1977, 15, 234–281. https://doi.org/10.1016/0022-2496(77)90033-5
13. Saaty T.L.; Majak. How to make a decision: The analytic hierarchy process. European Journal of Operational Research 1991, 48, 9–26. https://doi.org/10.1016/0377-2217(90)90057-I
14. Wu, J.; He, Y.; Zhao, J.L. An infrared target images recognition and processing method based on the fuzzy comprehensive evaluation. IEEE Access 2024, 12, 12126–12137. https://doi.org/10.1109/ACCESS.2024.3355157
15. Zheng, W.Q.; Xu, X.S.; Wang, Z.C. Fuzzy comprehensive evaluation of collapse risk in mountain tunnels based on game theory. Applied Sciences 2024, 14, 5163. https://doi.org/10.3390/app14125163
16. Peng, D.; Wei, T.; Zhao, H. Information security risk assessment of control systems in thermal power plants based on D-AHP and TOPSIS. Control and Decision 2019, 34, 2445–2451. https://link.cnki.net/doi/10.13195/j.kzyjc.2019.0240
17. Wu, B.; Wei, Y.; Meng, G. Multi-source monitoring data fusion comprehensive evaluation method for the safety status of deep foundation pit. Sustainability 2023, 15, 11809. https://doi.org/10.3390/su151511809
18. Li, W.T.; Yin, H.Y.; Song, Y.L. Evaluating the risk of social isolation in older people: AHP-fuzzy comprehensive evaluation. Risk management and healthcare policy 2023, 16, 79–92.https://doi.org/10.2147/RMHP.S383031
19. Luo, D.J.; Huang, J.; Liang, Y. Comprehensive evaluation of green mine construction level considering fuzzy factors using intuitionistic fuzzy TOPSIS with kernel distance: AHP-Fuzzy Comprehensive Evaluation. Environmental Science and Pollution Research 2024, 31, 16884–16898. https://doi.org/10.1007/s11356-023-31812-x