Construction and Experimental Study on Subjective Evaluation System of Braking Performance of New Energy Vehicle ABS System

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Abstract. Based on the defects of the objective evaluation index of braking performance of new energy vehicle ABS system, this paper constructs the subjective evaluation system of braking performance of New energy vehicle ABS system by using analytic hierarchy process (AHP), and designs subjective evaluation test table for ABS system and carries out road test. The test results show that the constructed ABS subjective evaluation system test is consistent with the objective evaluation index, and can feedback the driver's subjective feelings, which can be used as the final evaluation of the new car market.

1. Introduction
The evaluation indexes of the braking performance of the automobile include: braking efficiency, constancy of braking efficiency, and directional stability during braking.

After the new energy vehicle is equipped with the ABS system, the braking performance is improved. The evaluation of braking performance of new energy vehicles includes objective evaluation and subjective evaluation. Subjective evaluation is a supplement and extension of objective evaluation. It can further evaluate the project that objective evaluation does not reflect the potential of the vehicle ABS system. For the subjective evaluation of the braking performance of new energy vehicles, the following objectives need to be achieved:

(1) For the objective evaluation, after scoring the individual performance corresponding to the subjective evaluation, and combining the weight of index calculation, the braking performance of the whole vehicle is quantified, which is convenient for comparing the ABS systems of different models;
(2) If the subjective evaluation score is not ideal, the indicators with significant weights can be prioritized or improved.

2. Subjective evaluation project for braking performance of new energy vehicle ABS system
The subjective evaluation of braking performance of new energy vehicle ABS system mainly includes braking efficiency [4], constancy of braking efficiency [4], linear braking stability [4], corner braking stability [1], and handling and stability [7] of new energy vehicle ABS system, braking comfort for new energy, braking sensitivity of ABS system for new energy vehicles, and feedback performance for ABS system.
3. Subjective evaluation index of braking performance of new energy vehicle ABS system and determination of its weight

The subjective evaluation of the braking performance of the new energy vehicle ABS system is a complex problem with multiple levels and multiple indicators. The AHP can quantitatively analyze the nature, influencing factors and internal relations of these complex and dependent decision problems.

3.1. The basic principle of AHP

The AHP can transform the intricate and ambiguous structural relationships into quantitative analysis. Modeling by AHP can be carried out in the following four steps [2]:

(1) Building a hierarchical model
When applying AHP to analyze decision problems, we must first organize and layer the problem and construct a hierarchical structure model. Under this model, complex problems are broken down into components of the element. These elements form several levels according to their attributes and relationships. The elements of the previous level act as criteria to dominate the next level of related elements. These levels can be divided into three categories:

(i) The highest level: there is only one element in this level. Generally, it is the intended target or ideal result of analyzing the problem, so it is also called the target layer.

(ii) The middle layer: this level contains the intermediate links involved in achieving the goal. It can be composed of several levels, including the criteria and sub-criteria to be considered, and is therefore also called the criteria layer.

(iii) The bottom layer: this level includes various measures, decision-making schemes, etc., which are available for the realization of the target, and is therefore also called the measure layer or the plan layer.

The number of layers in the hierarchical structure is related to the complexity of the problem and the level of detail required for analysis. The number of layers is generally not limited. The elements governed by each element in each level should generally not exceed nine. This is because too many elements are dominant, which will make it difficult to compare the two.

(2) Constructing a judgment matrix in which each factor is compared with each other through expert consultation
It is necessary to compare the influence of n factors on the target A, so as to determine their proportion in A. Take two factors y_i and y_j at a time, and use a_{ij} to express the ratio of the influence of y_i and y_j on A. I and j take 1 to 9 respectively, and measures a_{ij}, then the n compared elements form a judgment matrix of pairwise comparison. Obviously, the judgment matrix satisfies:

\[ a_{ij} > 0, a_{ji} = \frac{1}{a_{ij}} (i, j = 1,2,\ldots,n) \] (1)

The determination of the value of a_{ij} refers to the numbers 1~9 and its reciprocal as the scale [5], as shown in Table 1:

| Scale | Meaning                                      |
|-------|----------------------------------------------|
| 1     | Compared with the two factors, they are both important. |
| 3     | Compared with the two factors, the former is slightly more important than the latter. |
| 5     | Compared with the two factors, the former is obviously more important than the latter. |
| 7     | Compared with the two factors, the former is mightily more important than the latter. |
| 9     | Compared with the two factors, the former is extremely more important than the latter. |
| 2, 4, 6, 8 | The intermediate value of the above adjacent judgment. |

| reciprocal | If the ratio of the importance of factor i to factor j is a_{ij}, then the ratio of factor j to factor i is a_{ji} = \frac{1}{a_{ij}}. |

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**Table 1.** a_{ij} scale.
(3) Calculate the relative weight and consistency test of each indicator under a single factor

The judgment matrix A corresponds to the feature vector W of the maximum eigenvalue $\lambda_{\text{max}}$, and after normalization, it is the ranking weight of the corresponding factor of the same level for the relative importance of a factor of the previous layer. The elements of the matrix are normalized by column:

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

The normalized elements are added by row, and the result is:

$$a'_{ij} = \sum_{j=1}^{n} a'_{ij} \quad (3)$$

The sum of the rows is normalized to obtain the weight of the column elements $W_i$:

$$w_i = \frac{a'_{i}}{\sum_{i=1}^{n} a'_{i}} \quad (4)$$

The maximum eigenvalue $\lambda_{\text{max}}$ of the judgment matrix is calculated:

$$\lambda_{\text{max}} = 1 - \frac{1}{n} \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} w_j}{w_j} \quad (5)$$

Since eigenvalue continuously depends on $a_{ij}$, the more $\lambda_{\text{max}}$ is larger than n, the more serious the degree of inconsistency A, and the more the normalized feature vector corresponding to $\lambda_{\text{max}}$ can not truly reflect the proportion of the influence of each index on the target. Therefore, it is necessary to make a consistency check on the provided judgment matrix to decide whether it can be accepted. The consistency test (CI) is calculated as follows:

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1} \quad (6)$$

$$CR = \frac{CI}{RI},$$

CR is called random consistency ratio, and the value of CR is calculated. If CR<0.1, the consistency of the judgment matrix is considered acceptable, otherwise the judgment matrix should be appropriately modified.

| n | 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 |

(4) Calculating combined weight vector and consistency test
Set a level (A layer) containing \( A_1, A_2, \ldots, A_n \) and a total of \( m \) factors, their total ordering weights are \( a_1, a_2, \ldots, a_n \). The next level (layer) is further composed of \( n \) factors \( B_1, B_2, \ldots, B_n \) and their hierarchical single order weights for \( A_j \) are \( b_{1j}, b_{2j}, \ldots, b_{nj} \) (when \( B_i \) and \( B_j \) are not associated, \( b_{ij} = 0 \)). Now we want the weight of each factor in the B layer about the total goal, that is, the total ranking weight of the factors of the B layer \( b_{1}, b_{2}, \ldots, b_{n} \):

\[
b_j = \sum_{j=1}^{m} b_{ij} a_j
\]

Let the pairwise comparison judgment matrix of the factors related to \( A_j \) in the B layer pass the consistency test in the single order, and find the single sort consistency index as \( CI(j) \), (\( j=1, \ldots, m \)), and the corresponding average of random consistency index is \( RI(j) \) (CI(j), RI(j) has been obtained when the hierarchical single order is sorted), then the B-level total order random consistency ratio is:

\[
CR = \frac{\sum_{j=1}^{m} CI(j) a_j}{\sum_{j=1}^{m} RI(j) a_j}
\]

When \( CR < 0.10 \), it is considered that the total ranking result of the hierarchy has a satisfactory consistency and accepts the analysis result.

3.2. Calculation and Determination of the Weight of Subjective Evaluation Index of Braking Performance of New Energy Vehicle ABS System
According to the evaluation project, a hierarchical mechanism model as shown in Fig. 1 is established. After the security inspection agency entrusts an ABS test engineer of a certain automobile company to quantitatively analyze the contents and test methods of the evaluation project, they judge the criterion layer and sub-criteria layer of each level analysis method according to their own evaluation experience and professional theoretical knowledge. The judgement obtained the results of Table 3.

![Figure 1. Subjective evaluation hierarchical mechanism model of braking performance of new energy vehicle ABS system](image-url)
Table 3. Subjective evaluation criteria layer and weight of braking performance of new energy vehicle ABS system

| Criteria layer B | B1   | B2   | B3   | B4   | B5   | B6   | B7   | B8   |
|------------------|------|------|------|------|------|------|------|------|
| B1               | 1    | 1    | 1    | 1/2  | 1    | 1    | 1    | 1/2  |
| B2               | 1    | 1    | 1    | 1/2  | 2    | 2    | 1    | 1/2  |
| B3               | 1    | 1    | 1    | 1/2  | 1    | 2    | 1    | 1/2  |
| B4               | 1/2  | 1/2  | 1/2  | 1/2  | 2    | 1    | 2    | 1/2  |
| B5               | 1/4  | 1/4  | 1/4  | 1/4  | 1    | 2    | 1/2  | 1/2  |
| B6               | 1/4  | 1/4  | 1/4  | 1/4  | 1/2  | 1/2  | 1    | 1/4  |
| B7               | 1    | 1    | 1    | 1    | 1    | 2    | 2    | 1    |
| B8               | 1    | 1    | 1    | 2    | 4    | 1    | 1    |      |
| Total            | 6    | 6    | 6    | 11   | 38/2 | 23   | 7    | 25/4 |

Calculate $b_{ij}$ and $W_i$ according to formula (2), formula (3) and Table 3. The calculation results are shown in Table 4.

Table 4. The calculation results of $b_{ij}$ and $W_i$

| $b_{ij}$ = $\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}$ | B1   | B2   | B3   | B4   | B5   | B6   | B7   | B8   | W    |
|-------|------|------|------|------|------|------|------|------|------|
| B1    | 4/24 | 4/24 | 4/24 | 2/11 | 8/38 | 4/23 | 1/7  | 4/25 | 0.1711|
| B2    | 4/24 | 4/24 | 4/24 | 2/11 | 8/38 | 4/23 | 1/7  | 4/25 | 0.1711|
| B3    | 4/24 | 4/24 | 4/24 | 2/11 | 8/38 | 4/23 | 1/7  | 4/25 | 0.1711|
| B4    | 2/24 | 1/11 | 1/11 | 4/38 | 2/23 | 2/3  | 1/4  | 2/5  | 0.0945|
| B5    | 1/24 | 1/12 | 1/22 | 2/38 | 2/23 | 1/4  | 1/4  | 1/25 | 0.0577|
| B6    | 1/24 | 1/12 | 1/22 | 2/38 | 2/23 | 1/4  | 1/4  | 1/25 | 0.0440|
| B7    | 4/24 | 4/24 | 4/24 | 1/11 | 4/38 | 2/23 | 1/7  | 4/25 | 0.1358|
| B8    | 4/24 | 4/24 | 4/24 | 2/11 | 4/38 | 4/23 | 1/7  | 4/25 | 0.1580|

The largest eigenvalue is:

$$AW = \begin{bmatrix}
4 & 4 & 4 & 2 & 8 & 4 & 1 & 4 \\
24 & 24 & 24 & 11 & 38 & 23 & 7 & 25 \\
4 & 4 & 4 & 2 & 8 & 4 & 1 & 4 \\
24 & 24 & 24 & 11 & 38 & 23 & 7 & 25 \\
4 & 4 & 4 & 2 & 8 & 4 & 1 & 4 \\
24 & 24 & 24 & 11 & 38 & 23 & 7 & 25 \\
2 & 2 & 2 & 1 & 4 & 2 & 1 & 2 \\
24 & 24 & 24 & 11 & 38 & 23 & 7 & 25 \\
1 & 1 & 1 & 1 & 2 & 2 & 1 & 2 \\
24 & 24 & 24 & 11 & 38 & 23 & 14 & 25 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
24 & 24 & 24 & 11 & 38 & 23 & 14 & 25 \\
4 & 4 & 4 & 1 & 4 & 2 & 1 & 4 \\
24 & 24 & 24 & 11 & 38 & 23 & 7 & 25 \\
4 & 4 & 4 & 2 & 4 & 4 & 1 & 4 \\
24 & 24 & 24 & 11 & 38 & 23 & 7 & 25
\end{bmatrix}
\begin{bmatrix}
0.1711 \\
0.0945 \\
0.0577 \\
0.1487 \\
0.1580
\end{bmatrix} = \begin{bmatrix}
0.1672 \\
0.1672 \\
0.1672 \\
0.0933 \\
0.0451 \\
0.1487 \\
0.1611
\end{bmatrix} = nW$$
From formula (5):

$$\lambda_{\text{max}} = \left[ \begin{array}{cccc}
0.1672 & 0.1672 & 0.1672 & 0.0933 \\
0.0945 & 0.0549 & 0.0451 & 0.1487 \\
0.0440 & 0.0577 & 0.0440 & 0.1358 \\
0.1711 & 0.1711 & 0.1711 & 0.1580 \\
\end{array} \right] = 8.0100$$

From (6), CI=0.0014. According to Table 2, the consistency ratio CR = 9.929e-004 < 0.1, so the judgment matrix has consistency. Get the weight vector as:

$$W = [0.1672 \ 0.1672 \ 0.1672 \ 0.0933 \ 0.0549 \ 0.0451 \ 0.1487 \ 0.1611]^T$$

Calculate weights of braking effectiveness sub-criteria, shown in Table 5:

| B1-C Criteria | C1  | C2   | C3   | $W$ |
|---------------|-----|------|------|-----|
| C1            | 1   | 1/3  | 1/6  | 0.0960 |
| C2            | 3   | 1    | 1/3  | 0.2510 |
| C3            | 6   | 3    | 1    | 0.6530 |
| Total         | 10  | 13/3 | 9/6  |     |

$$A_{B1}W_{B1-C} \begin{bmatrix} 0.1015 \\ 0.2318 \\ 0.6667 \end{bmatrix} \Rightarrow \lambda_{\text{max}} = 3.0018 \Rightarrow CI = 9.0000e-004, CR = 0.0017 < 0.1$$

The weight judgment matrix of the brake efficiency sub-criteria passes the consistency test. Therefore, the weight vector of the brake sub-criteria is:

$$W_{B1-C} = [0.0960 \ 0.2510 \ 0.6530]^T$$

Use the same method, other weight vector are:

$$W_{B6-C} = [0.3333 \ 0.3333 \ 0.3333]^T$$

$$W_{B7-C} = [0.3333 \ 0.3333 \ 0.3333]^T$$

$$W_{B8-C} = [0.3333 \ 0.3333 \ 0.3333]^T$$

It can be known from the calculation results that the consistency of the weights of each sub-criteria under a single factor is less than 1, that is, the consistency test is passed.

Finally, the same method is used to judge the overall consistency, and the results are also passed the consistency test. Finally, the calculated subjective evaluation weight of the braking performance of the new energy vehicle ABS system is shown in Fig. 2:
Figure 2. The Weight of Subjective Evaluation for ABS Automobile Brake Performance

It can be seen from Fig.2 that in the average indicator of the subjective braking performance of the ABS system of the new energy vehicle, the weights of the braking efficiency, the constancy of braking efficiency and the linear braking stability are equal, accounting for 50.16% of the total weight, which guarantees the basic braking performance of the car. The weight of feedback, corner stability and sensitivity are also relatively heavy. These three performances are the embodiment of the superiority of different ABS systems. Under the satisfying the basic braking performance, the engineers are more demanding on the ABS system. Paying attention to the potential of the system, such as cornering brake [3], is a content that objective evaluation indicators cannot be evaluated at present, but it is precisely the potential of ABS.

4. Vehicle test verification and conclusion

In order to verify the practicality of the subjective evaluation of the braking performance of the new energy vehicle ABS system, this paper selects a certain new energy vehicle with hydraulic ABS system (numbered as test vehicle 1) to conduct subjective evaluation test on August 14, 2018. The test was conducted according to the subjective evaluation method established in this paper, and the manufacturer was commissioned to conduct a road test to compare the results of subjective evaluation and road test evaluation.

In this subjective evaluation test, two experienced engineers were invited to carry out the ABS braking performance evaluation test. The scores of the two engineers are as follows, shown in Table 6:
Table 6. Subjective evaluation test score

| Evaluation project | Engineer 1 | Engineer 2 | Average score |
|--------------------|------------|------------|---------------|
|                    | Score      | Record     | Score         | Record     |               |
| B1                 | 7          | —          | 8             | —          | 7.5           |
| B2                 | 6          | braking performance decreases after repeated braking | 6          | multiple brake deviation | 6          |
| B3                 | 6          | left deviation | 6          | left deviation | 6          |
| B4                 | 5          | deviation  | 4             | deviation  | 4.5           |
| B5                 | 6          | —          | 7             | —          | 6.5           |
| B6                 | 6          | —          | 7             | —          | 6.5           |
| B7                 | 7          | —          | 7             | —          | 7             |
| B8                 | 5          | scream     | 6             | noise      | 5.5           |
| Total weight by weight | 6.0897    |            | 6.4247        |            | 6.1875        |

Since the subjective evaluation total score is greater than 6, so the braking performance of the vehicle is qualified, but there are problems such as deviation and noise. As can be seen from the scores of the two engineers, there are problems with brake stability and noise that require further testing.

According to the requirements of the task, the road test is carried out on the ABS performance of the test vehicle 1. The road test conditions [8] are: temperature 33°C, humidity 52%, wind speed 3m/s, the test results are as follows:

1. On the split pavement (left side is on the low adhesion coefficient road surface, \( \varphi \leq 0.4 \); right side is on the high adhesion coefficient road surface, \( \varphi \geq 0.8 \)), the right front wheel slip increase suddenly on the high adhesion coefficient road and leads to the tire scream;
2. When the ABS is working, the noise of the pump is unacceptable;
3. On the high adhesion coefficient road, when the initial speed is 80km/h, the vehicle will slightly shift to the left when the vehicle approaches the stop (deviation is 100mm). When the initial speed is 100km/h, the vehicle also slightly shifts to the left. When the braking interval is short (that is, after the brake temperature rises), the vehicle is slightly worse to the left. (Deviation is 300mm). When the initial speed is 140km/h and the brake is nearing the end, the vehicle has a significant left-to-left deviation, which is about 700mm. At low speeds, the brakes hardly feel the deviation.

Reason: The car's tires are not in use. The Goodyear tires are required, and the car uses Hankook tires.

Conclusion: The performance of the vehicle 1 meets the requirements of GB13594-2003.

From the road test results of the manufacturer, it can be seen that the subjective evaluation is basically consistent with the road test evaluation, and the problems of the test vehicle 1 are effectively judged, thus verifying that the subjective evaluation method and weight establishment of this paper are reasonable and feasible.

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