Evaluation Method of Highway Safety Maintenance Based on the Two-Dimensional Cloud Model Considering Equilibrium

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Abstract—In recent years, the total length of highways in service has been continuously increasing, and the demand for highway transportation has also increased. The damages and defects of highway and its supporting facilities with aging have serious effects on operation efficiency and driving safety. This paper studied the evaluation method of highway safety maintenance to assess the safety condition of highway and its supporting facilities. Firstly, an evaluation index system of highway safety maintenance was established from two major aspects: road structure and environment conditions, safety protection and management conditions. Secondly, the impact of discrete degree of index scores on the evaluation result of cloud model was analyzed, and then the equilibrium fine-tuning factor was proposed to improve the weighted mode between weights and scores. Based on the two-dimensional cloud model, a general process of safety evaluation considering the equilibrium fine-tuning factor was thus developed, and a cloud similarity algorithm based on the membership degree method was also proposed. Finally, a numerical study was carried out to validate the proposed model, and the sensitivity analysis of equilibrium significance α was conducted. The results showed that the impact of equilibrium fine-tuning factor on the comprehensive evaluation result is unneglectable, and the proposed method conforms to the reality of safety evaluation better, which can be applied in the highway safety maintenance evaluation for future reference.

1. INTRODUCTION

The highway safety issue is the most serious among the major ways of transportation such as railway, aviation, and waterway. According to the World Health Organization Global Road Safety Status Report 2018 [1], the number of road traffic deaths continues to rise with 1.35 million deaths each year. The highway system consists of roadbed, sidewalk, safety and management facility, greening and other components, which interact to determine the level of operational safety services. However, due to continuous exposure to heavy traffic and surroundings, the highway and its supporting facilities suffer varying degrees of deteriorations and damages during the highway operation. These damages and defects seriously affect operational efficiency, especially traffic safety. Although the advent of automatic driving era can help to reduce the human-error accidents, these damages and defects will still pose a serious potential safety hazard to driving safety.

For decades, highway safety maintenance has always been the main concern of researchers, which aims to reduce the possibility and severity of accidents and improve traffic safety. The evaluation of highway safety maintenance is a classic method to find shortcomings through checking and evaluating
various highway indexes. To construct a suitable and comprehensive evaluation index system, many efforts have been made to investigate the highway system components. Obaze-Igbinedion and Owolabi [2] proposed a pavement sustainability index that involves some major transportation sustainability indexes, such as environmental, social, and economic impacts, and correlated them to pavement evaluation indexes, such as serviceability, structural capacity, skid resistance, and pavement surface distress. Zhu and Lu [3] established an index system from four aspects, including roadbed and pavement, safety facilities, management facilities and road greening, and collected data from an on-board video for each index. Marcelino et al. [4] proposed that machine learning methods could help to develop the pavement condition indicators and improve the accuracy of indicators when the available data are less. Weng et al. [5] studied the concept and influencing factors of road lighting visibility. In addition, the evaluation method is also the key to determine the scientific nature and accuracy of evaluation. Researchers have conducted a lot of research in the long-term evaluation practice and formed dozens to hundreds of evaluation methods. These methods can be roughly divided into two categories: one is the statistical methods, such as linear regression analysis, while the other is the typical comprehensive evaluation models, such as analytic hierarchy process (AHP), fuzzy mathematics theory (FMT), comprehensive index method (CIM) and other related improved models, e.g., the cask evaluation model based on fuzzy and cask theory [6]. Fakhri and Dezfoolian [7] presented a practical solution for pavement structural evaluation based on artificial neural network and regression models, which leads to accurate evaluation results. Wang et al. [8] analyzed and evaluated the roadbed conditions using an improved AHP. Lou and Lu [9] divided the road evaluation into two parts: intersections and sections according to the road function and differences, and employed CIM to model the evaluation process.

Since there are lots of uncertainty factors in the evaluation process, the probability theory and fuzzy mathematics are usually applied to the evaluation. And it was pointed out after years of research that randomness and fuzziness are the basic elements of uncertainty. Because of the shortcomings of probability theory and fuzzy mathematics in dealing with uncertainty, Li et al. [10] proposed the cloud theory based on the probability theory and fuzzy mathematics, and built the correlation between the fuzziness and randomness. Based on the cloud theory, the cloud model was developed as a qualitative and quantitative conversion model. In recent years, cloud theory and models have been widely used in various evaluation studies [11]-[19]. However, there are few studies concerning the improvement of cloud model in safety evaluation. To fill this gap, this paper proposes the equilibrium fine-tuning factor and combines it with the cloud model. And also, a non-equidistant evaluation criterion is applied in this paper to enlarge the impact of low index scores on the evaluation results. A cloud similarity algorithm based on the membership degree method is thus developed to adapt to these new characteristics. The rest of the paper is organized as follows. Section 2 establishes the multi-index system of highway safety maintenance evaluation. Section 3 presents the basic theory of cloud model. Section 4 illustrates the method of weight determination, and proposes the equilibrium fine-tuning factor and the general evaluation process based on two-dimensional (2D) cloud model. Section 5 conducts a numerical analysis and emphasizes the significance of equilibrium fine-tuning factor for safety evaluation. Section 6 concludes the paper.

2. EVALUATION INDEX SYSTEM
We perform an in-depth analysis on the main risk sources of highway and summarize four major aspects: road structure, road environment, safety protection, and traffic management facility. Then, a multi-index evaluation system of highway safety maintenance is established, and from the perspective of the highway itself and its management, the first-level index is divided into two parts: road structure and environment conditions (RSEC) and safety protection and management conditions (SPMC). The first-level index of RSEC includes three two-level indexes, i.e., road alignment, structure technical condition, and road environment, with 2, 3, and 4 third-level indexes, respectively. And the first-level index of SPMC includes four two-level indexes, i.e., protective facility, isolation facility, sign and marking, and traffic light, with 2, 2, 2, and 2 third-level indexes, respectively. The detailed multi-index
evaluation index system of highway safety maintenance is shown in Fig. 1. The third-level indexes are the basis of the entire index system, which are used to determine the upper-level indexes.

The evaluation criterion $G$ is commonly divided into five grades, namely $G = \{\text{Excellent, Good, Medium, Inferior, Poor}\}$, and usually adopts the method of equidistant division for score interval. To magnify the impact of unsafe factors on the evaluation results, a non-equidistant scoring criterion is employed [20] and shown in Table 1.

**Figure 1.** Multi-index evaluation system of highway safety maintenance.

| Evaluation grade | Score interval | Meaning | Cloud digital feature |
|------------------|----------------|---------|----------------------|
| V                | [90, 100]      | Excellent: compliance with safety standards | (95,1.6667,0.2; 95,1.6667,0.2) |
| IV               | [80, 90)       | Good: relative safety                      | (85,1.6667,0.4; 85,1.6667,0.4) |
| III              | [70, 80)       | Medium: slight danger                      | (75,1.6667,0.6; 75,1.6667,0.6) |
| II               | [60, 70)       | Inferior: danger                           | (65,1.6667,0.8; 65,1.6667,0.8) |
| I                | [0, 60)        | Poor: serious danger                       | (30,10.000,1.0; 30,10.000,1.0) |

**TABLE I.** EVALUATION CRITERION AND CORRESPONDING CLOUD DIGITAL FEATURES.
3. CLOUD MODEL THEORY

3.1. Basic concept of cloud
The cloud theory expresses the fuzzy concept utilizing the “cloud” concept with a fuzzy boundary. The “cloud”, which is usually assumed to follow a normal distribution, can be represented by the digital feature, namely mathematical expectation $E_x$, entropy $E_n$, and hyper entropy $H_e$. There is a combination of fuzziness and randomness. Assume that $Z$ is a quantitative domain which can be accurately represented by quantitative values $x$, and that $D$ is the qualitative concept on $Z$. Then $\forall x \in Z, x \rightarrow \mu(x)$, where $\mu(x)$ denotes the membership degree of $x$ to $D$, and $\mu(x) \in [0,1]$. Thus, domain $Z$ can be mapped to the interval $[0, 1]$. The mapping, that is, the distribution of membership degree on the domain $Z$, is called membership cloud, and each $x$ denotes a cloud droplet.

3.2. Digital feature of security cloud
The cloud model is used to describe the process of uncertain transformation between qualitative and quantitative concepts. The calculation of security cloud is an important step in converting the exact data into qualitative concepts represented by digital feature, which is referred to as a backward cloud generator. Suppose that the expert scoring method is employed to evaluate the third-level indexes. Then each index will generate a security cloud, and the score of each expert for the index denotes a cloud droplet. The equations to calculate the digital feature of security cloud read

$$
\begin{align*}
E_s^i &= \frac{1}{q} \sum_{i=1}^{q} s_q \\
E_n^i &= \sqrt{\frac{1}{q} \sum_{i=1}^{q} (E_s^i - E_s^i)^2} \\
H_s^i &= \frac{1}{q-1} \sum_{i=1}^{q} (E_s^i - E_s^i)^2
\end{align*}
$$

(1)

where $E_s^i$, $E_n^i$, and $H_s^i$ denote the mathematical expectation, entropy, and hyper entropy of security cloud of index $j$, respectively; $s_q$ denotes expert $i$’s score on index $j$; $S_j$ denotes the score standard deviation of index $j$; $q$ denotes the number of experts.

3.3. Digital feature of standard cloud
The distribution of standard clouds is related to the score interval of evaluation criterion. An evaluation grade with a score interval $[S_{\text{min}}, S_{\text{max}}]$ can be described using a standard cloud, whose digital feature is calculated as follows

$$
\begin{align*}
\hat{E}_s^j &= \frac{S_j - S_{\text{min}}}{2} \\
\hat{E}_n^j &= \frac{S_{\text{max}} - S_{\text{min}}}{6} \\
\hat{H}_s^j &= k
\end{align*}
$$

(2)

where $S_{\text{max}}$ and $S_{\text{min}}$ are the maximum and minimum of score interval of evaluation grade $j$, respectively; $\hat{E}_s^j$, $\hat{E}_n^j$, and $\hat{H}_s^j$ denote the mathematical expectation, entropy, and hyper entropy of standard cloud of evaluation grade $j$, respectively; $k$ is a constant, which can be adjusted according to ambiguity. Here, we adopt a gradual increasing method from the highest grade to the lowest grade to strengthen the strictness of high grade.
In this paper, the two first-level indexes are regarded as the two dimensions of 2D cloud model, and the same score interval is applied to the two first-level indexes. So, the digital feature of standard cloud of grade-$j$ in 2D cloud model can be expressed as $\hat{E}_s^{i,j}, \hat{E}_n^{i,j}, \hat{H}_e^{i,j}$, where $i$ and $n$ denote the two first-level indexes: RSEC (I) and SPMC (II), respectively. The standard cloud digital features of each evaluation grade are shown in Table 1. This is done to identify whether the shortcoming of highway safety lies in the highway itself or its management under the aforementioned evaluation index system.

4. Weight determination and cloud model evaluation process

4.1. Index weight

The weighting method can be roughly divided into the subjective one, such as AHP, and the objective one, such as principal component analysis (PCA) [21][22]. Compared with the subjective one, the objective weighting method has the reliable mathematical theory and less artificial intervention [23][25]. The entropy weight method, one of objective weighting methods, is used to determine index weights in this paper, which reads

$$p_y = \frac{s_y}{\sum_{i=1}^{q} s_y}$$

$$e_j = -\frac{1}{\ln q} \sum_{i=1}^{q} (p_y \cdot \ln p_y)$$

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n} (1-e_j)}$$

where $p_y$ denotes the proportion of expert $i$'s score for index $j$; $e_j$ denotes the entropy of index $j$, and $\ln q$; $w_j$ denotes the weight of index $j$; $m$ denotes the number of indexes.

4.2. Calculation method of synthetic cloud

4.2.1. Linear weighted mode: In comprehensive evaluations, the linear weighted mode is commonly used for dealing with the relationship among indexes. Therefore, the evaluation process is a weighted superposition process from the subordinate indexes to the superior indexes, which reads

$$Y = W \cdot X$$

where $Y$ is the cloud digital feature of the superior index; $W = (w_1, w_2, \cdots, w_n)$ is the weight vector; $X = \begin{pmatrix} x_1, x_2, \cdots, x_n \end{pmatrix}$ is the cloud digital feature matrix of all indexes belonging to a common superior index; $x_j = (E_s^j, E_n^j, H_e^j)$, $\forall j = 1,2,\cdots,n$ is the vector of cloud digital feature; $n$ is the number of subordinate indexes.

4.2.2. Equilibrium fine-tuning factor: The “bucket theory”, one of safety management theories, enlightens that the capacity of a bucket depends on the shortest board. In analogy to highway safety, the safety of entire highway system is determined by the highway subsystem with the lowest safety. Motivated by the fact, an equilibrium fine-tuning factor is thus proposed to adjust the weighted mode. The factor is calculated based on the non-equilibrium degree of scores among indexes belonging to a common superior index [26]. Since the expectation $E_x$ in the three cloud digital can describe the qualitative concept best, the entropy $E'$ of expectation $E_x$ is used to measure the non-equilibrium degree of cloud digital features among the indexes, which reads

$$E' = \sum_{j=1}^{n} (1-e_j)$$
\[
\begin{align*}
E' &= -\sum_{j=1}^{n} (t_j \cdot \ln t_j) \\
T_j &= \frac{E'_j}{\sum_{j=1}^{n} E'_j}
\end{align*}
\]  
(5)

where \( n \) denotes the number of indexes belonging to a common superior index.

Then the equilibrium fine-tuning factor \( \gamma \) is defined as follows

\[
\gamma = \left( \frac{E'_\alpha}{E_{\max}} \right)^{\alpha}
\]  
(6)

where \( \alpha \) denotes the equilibrium significance; \( E_{\max} = \ln n \).

According to the mathematical nature of power function, the function is the convex one when \( \alpha > 1 \) in the interval of \([0, 1]\). In this case, the factor is more sensitive to the fluctuation near the steady state \( E' = E_{\max}' \) than that when \( \alpha < 1 \). Therefore, \( \alpha > 1 \) is more in line with our expectations. And the larger the \( \alpha \), the more significant the equilibrium effect.

In the past few years, the nonlinear weighted mode has captured more and more research interests. The equilibrium fine-tuning factor \( \gamma \) is first (to our knowledge) applied in the combination of cloud digital features and weights to revise the linear weighted superposition process. The nonlinear weighted mode is thus defined as follows

\[
Y = \gamma \cdot WX
\]  
(7)

It can be intuitively understood that the more discrete the cloud digital features of subordinate indexes, the smaller the weighted result. This is quite consistent with the characteristic of safety evaluation. Because the safety of entire system is determined by the subsystem with the lowest safety, the excessive difference among indexes is undesirable, which would lead to an unsafe condition, even if the evaluation result is pretty high due to the small index value corresponding to a small weight.

As an example, assume that the expectation \( E_s \) of cloud digital feature \( Y \) calculated by Eq. (4) is equal under two different datasets of \( X \), e.g.,

The weight vector \( W = [0.5, 0.2, 0.2, 0.1] \);

The dataset 1: \( X = \begin{pmatrix} 80 & 0.5 & 0.5 \\ 85 & 0.5 & 0.5 \\ 75 & 0.5 & 0.5 \\ 80 & 0.5 & 0.5 \end{pmatrix} \), and the dataset 2: \( X' = \begin{pmatrix} 100 & 0.5 & 0.5 \\ 90 & 0.5 & 0.5 \\ 50 & 0.5 & 0.5 \\ 20 & 0.5 & 0.5 \end{pmatrix} \). Then, the linear weighted result is \( W \cdot X = W \cdot X' = (80.05, 0.5, 0.5) \).

Although the weighted result is equal between the two datasets, one can see that cloud digital features in dataset 2 are much discrete than those in dataset 1, and some expectations are quite low in dataset 2. Next, we introduce the equilibrium fine-tuning factor \( \gamma \) to revise the weighted result. The equilibrium fine-tuning factor \( \gamma \) under \( \alpha = 1 \) calculated by Eq. (6) are 0.9993 and 0.9010 in the two datasets, respectively, and the nonlinear weighted results calculated by Eq. (7) are (79.9436, 0.45, 0.45) and (72.0818, 0.45, 0.45), respectively. It can be seen that the revised weighted result of dataset 2 is notably lower than the one of dataset 1, which is much closer to what we expected.

4.2.3. Cloud generator and cloud pattern analysis: Although the comprehensive evaluation cloud pattern can visually represent the relationship of relative position between synthetic cloud and standard clouds, it is difficult to quantify the similarity between them. The reciprocal of Euclidean distance between two cloud expectations has been widely used to measure the similarity between the two clouds. However, due to the use of non-equidistant evaluation criterion, the size and dispersion degree of standard clouds are totally different. Therefore, the methods, like Euclidean distance, are not suitable for non-equidistant evaluation criterion. To explore this issue, the membership degree method [27] is proposed to measure the similarity degree between synthetic cloud and standard clouds in the
one-dimensional cloud model.

Next, we extend the method to the two-dimensional situation. However, one problem emerges that when the synthetic cloud is far away from all standard clouds, the calculation results of membership degree are too small to distinguish. It does not need to be considered in the one-dimensional cloud model. Therefore, a modified cloud similarity algorithm is proposed in this paper. First map the synthesize cloud to the axis of $y = x$ as shown in Fig. 2, and then calculate the average membership degree of synthetic cloud droplets in each standard cloud. The grade corresponding to standard cloud with the greatest membership degree is selected as the final comprehensive evaluation result. The specific algorithm is reported as follows.

**Algorithm:** The modified cloud similarity algorithm base on the membership degree method.

**Input:** The digital feature of synthetic cloud $A = (E^I_x, E^S_x, H^I_x, E^S_x, H^S_x)$ and the digital feature of standard clouds $B^j = (\hat{E}^I_{x,j}, \hat{E}^S_{x,j}, \hat{H}^I_{x,j}, \hat{E}^S_{x,j}, \hat{H}^S_{x,j})$, $\forall j = 1, 2, \cdots, J$.

**Output:** The evaluation result $L$ and the similarity degree $\Phi = (\varphi_1, \varphi_2, \cdots, \varphi_J)$ between the synthetic cloud and $J$ standard clouds.

1. $\bar{E}^I_x = \frac{E^I_x + E^S_x}{2}$, $\bar{E}^S_x = \frac{E^S_x + E^S_x}{2}$
2. For $j = 1$ to $J$
3. For $k = 1$ to $N$
4. $\left(\frac{E^I_{x,k}, E^S_{x,k}}{N} = \left(\frac{E^I_x, H^I_x, E^S_x, H^S_x}{N}\right)\right)$
5. $(x_k, y_k) = N(\bar{E}^I_x, \bar{E}^S_x, \bar{H}^I_x, \bar{H}^S_x)$
6. $\left(\frac{\hat{E}^{I,j}_{x,k}, \hat{E}^{S,j}_{x,k}}{N} = \left(\frac{\hat{E}^{I,j}_{x,j}, \hat{H}^{I,j}_{x,j}, \hat{E}^{S,j}_{x,j}, \hat{H}^{S,j}_{x,j}}{N}\right)\right)$
7. $\mu_{j,k} = \exp\left(-\frac{1}{2} \times \frac{(x_k - \hat{E}^{I,j}_{x,k})^2 + (y_k - \hat{E}^{S,j}_{x,k})^2}{(\hat{E}^{I,j}_{x,k})^2 + (\hat{E}^{S,j}_{x,k})^2}\right)$
8. End For
9. $\varphi_j = \frac{1}{N} \sum_{k=1}^{N} \mu_{j,k}$
10. End For
11. $\Phi = (\varphi_1, \varphi_2, \cdots, \varphi_J)$
12. $L = \arg \max (\Phi)$

![](Figure 2. The sketch of synthetic cloud mapping.)
5. NUMERICAL ANALYSIS

5.1. Model application

According to the multi-index evaluation system and evaluation criterion, the third-level indexes are scored on the interval [0, 100] with precision 1, respectively. The scoring results are shown in Table 2. The digital features of security cloud of each third-level index are calculated by Eq. (1). And the weights of third-level indexes belonging to the two first-level indexes are calculated by Eq. (3) based on the scoring result, respectively.

| Index No. | Expert No. | 1  | 2  | 3  | 4  | 5  | 6  |
|-----------|------------|----|----|----|----|----|----|
| A1        | 90         | 92 | 91 | 95 | 93 | 95 |
| A2        | 94         | 94 | 96 | 95 | 95 | 95 |
| A3        | 98         | 98 | 99 | 94 | 93 | 94 |
| A4        | 76         | 75 | 74 | 70 | 73 | 72 |
| A5        | 97         | 95 | 97 | 97 | 98 | 99 |
| A6        | 89         | 92 | 94 | 93 | 90 | 90 |
| A7        | 93         | 92 | 93 | 88 | 89 | 93 |
| A8        | 90         | 92 | 91 | 93 | 92 | 91 |
| A9        | 88         | 87 | 90 | 91 | 87 | 90 |
| B1        | 85         | 84 | 85 | 84 | 80 | 84 |
| B2        | 72         | 74 | 73 | 74 | 75 | 76 |
| B3        | 95         | 97 | 98 | 97 | 94 | 95 |
| B4        | 94         | 95 | 95 | 96 | 95 | 94 |
| B5        | 98         | 99 | 95 | 96 | 96 | 94 |
| B6        | 84         | 82 | 79 | 83 | 83 | 84 |
| B7        | 87         | 83 | 89 | 87 | 84 | 85 |
| B8        | 95         | 94 | 93 | 95 | 96 | 94 |

The cloud digital features of two first-level indexes are (88.1504,2.1559,0.7166) and (85.8424,1.7033,0.6703), respectively, which are calculated from the nonlinear weighted superposition of subordinate indexes level by level considering the equilibrium fine-tuning factor under $\alpha = 1$. The comprehensive evaluation cloud patterns are plotted in Fig. 3. The similarity degrees calculated by the modified cloud similarity algorithm are 5.32e-14, 4.37e-45, 1.06e-10, 0.27, and 2.49e-5 for the Grade-I ~ Grade-V standard clouds, respectively. Therefore, the comprehensive evaluation result belongs to Grade-IV: relatively safe, and the conditions of RSEC and SPMC are basically the same.
5.2. Sensitivity analysis of equilibrium significance $\alpha$

Due to the impact of the equilibrium fine-tuning factor on the comprehensive evaluation result, the original nonlinear relationship between the index scores and comprehensive evaluation result becomes more complex. To further reveal the impact of equilibrium significance $\alpha$ on the comprehensive evaluation result, the sensitivity analysis is conducted. For convenience, the two weakest third-level indexes in RSEC and SPMC are employed as variables to change the dispersion degree of scores among indexes.

Fig. 4 shows the distribution pattern of comprehensive evaluation results under different $\alpha$. In Fig. 4(a), the equilibrium significance $\alpha$ is equal to 0, which means that the equilibrium fine-tuning factor $\gamma$ is invalid, and one can see that even though the scores of the two indexes are very low, the comprehensive evaluation result is always not bad, which is obviously unreasonable for safety evaluation. However, the Grade-I result can be first observed when $\alpha = 1$ in Fig. 4(b). It is showed that the equilibrium fine-tuning factor is very effective for the negativity of low score. When the equilibrium significance $\alpha$ becomes larger, the area of low grade also becomes larger. It indicates that the impact of low scores on the comprehensive evaluation results is gradually significant, which demonstrates that the introduction of equilibrium fine-tuning factor is quite necessary for safety evaluation.

![Distribution pattern of comprehensive evaluation results under different $\alpha$.](image)
Figure 4. The distribution patterns of comprehensive evaluation result under different equilibrium significance $\alpha$. The color represents the cloud similarity degree between the synthetic cloud and the affiliated standard cloud.

6. CONCLUSIONS

In recent years, the evaluation of highway safety maintenance has been a hot topic in academic research. Relatively abundant achievements have been obtained with the limitations mainly concentrating on three aspects that are the selection of evaluation index factors, the reasonable distribution of index weight, and the selection of comprehensive evaluation methods with the randomness and fuzziness. Combining the safety theory that risks are everywhere and dangers always lie in the weakness, namely “bucket theory”, this paper investigates the method of safety evaluation from a new perspective. The main contributions include:

- The equilibrium fine-tuning factor is proposed to capture the “irregularity of the bucket board”, that is, the lopsided scores among evaluation indexes.
- A multi-index evaluation system is established considering the conditions of the highway itself and its management facilities, and the non-equidistant evaluation criterion is adopted to magnify the impact of unsafe factor scores on the evaluation result.
- The evaluation model of highway safety maintenance is developed based on 2D cloud model, and a cloud similarity algorithm between synthetic cloud and standard clouds for 2D cloud model is improved.
- The sensitivity analysis is conducted and the impact of equilibrium significance $\alpha$ is analyzed to better understand the importance of equilibrium fine-tuning factor.

The results show that it is quite necessary to introduce the equilibrium fine-tuning factor in the safety evaluation, which makes the evaluation result more in line with our expectations. Therefore, the proposed method conforms to the reality of safety evaluation better, which can be applied in the highway safety maintenance evaluation for future reference. In the future study, the evaluation index system should be further studied to reduce the correlation and quantify as much as possible.

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