Comprehensive evaluation model of freeway traffic safety considering subjective and objective factors

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Abstract. In order to accurately evaluate the level of freeway traffic safety, this paper analyzed the characteristics of accidents on freeway and the factors affecting the freeway traffic safety, established an evaluation index system for freeway traffic safety, and constructed a comprehensive evaluation model based on hierarchical entropy and a comprehensive evaluation model based on vector similarity. The hierarchical entropy evaluation model used the analytic hierarchy process (AHP) and the entropy weight method to determine the subjective and objective weights of the evaluation indexes, the weighted average of the index data and the evaluation results. The vector similarity evaluation model used the vector similarity degree to analyze the traffic safety status of the freeway and conduct a comprehensive analysis.

1. Introduction
In recent years, China's expressway has developed rapidly. By the end of 2018, the total mileage of China's expressway has broken through 140,000 km. On the one hand, the development of expressway has led to the development of China's economy and improved people's living standards; on the other hand, the frequent traffic accidents on expressways have sounded the safety alarm. Scholars at home and abroad have done a lot of research work on expressway traffic safety. For example, LAURESHYN et al. [1] constructed a framework for judging traffic safety level based on behavior data at the micro level; Dang Xiaoxu et al. [2] established a generalized data envelopment analysis and evaluation model for road traffic safety with data packet. The road traffic safety level of nine countries, including China, from 2000 to 2012, was evaluated. Bi Hezheng et al. [3] used grey cluster evaluation method to analyse the index system. The intersection safety level was divided into five grades, and an example was applied. The above studies mostly make subjective evaluation or objective evaluation separately when determining the weight of indicators, but few combine the two methods. At the same time, many methods have narrow evaluation scope and long evaluation time, lacking adaptability and unity. In view of this, considering human, vehicle, road, environment and accident factors, the author will construct hierarchical entropy evaluation model and vector similarity evaluation model, and apply these two models to expressway of Jiangsu to evaluate its traffic safety level, in order to verify the validity of the model.

2. Evaluation index system of expressway traffic safety
Firstly, some evaluation indicators were selected, and then an evaluation index system was constructed based on the principle of establishing the index system. Finally, the evaluation indicators were quantified.
2.1. Determination of evaluation index

Starting from the large-scale transportation system, the general research is to select some evaluation indicators from four aspects of people, vehicles, roads and environment. [4] Considering that traffic accidents are the feedback of traffic safety risks, the author established the evaluation index system of expressway traffic safety from five aspects: people, vehicles, roads, environment and accidents. Because the evaluation index system obtained from the primary selection was not perfect enough, further screening was needed. [5] After testing the representativeness, certainty, sensitivity and independence of the primary evaluation indicators, 12 secondary indicators were selected to construct the evaluation index system, taking accident indicators, human indicators and environmental indicators as the first-level indicators.

2.2. Quantitative Function of Evaluation Index

After the establishment of the evaluation index system for expressway traffic safety, in order to calculate conveniently in case analysis, construct functional relationship in model building and realize quantitative evaluation, 12 secondary evaluation indexes were quantified. The results of quantitative evaluation are as follows:

1) Total number of deaths $T_d$
2) Mortality rate $R_d$
3) Equivalent ten thousand vehicle mortality rate $R_n$
4) Mortality rate of 100,000 people $\varepsilon$
5) Decline ratio in the number of deaths $\tau$
6) Traffic hazard factor $\lambda$

$$\lambda = \frac{T_d + T_h}{c \times \rho}$$  \hspace{1cm} (1)

$T_h$ is the total number of injuries in expressway accidents; $c$ is the total population and $\rho$ is the number of trips per capita per year.

7) Driver safety knowledge level $S$

$$S = \frac{S_1 + S_2 + \cdots + S_n}{n}$$  \hspace{1cm} (2)

$n$ is the number of samples; $S_1, S_2, \cdots, S_n$ is the score of $n$ samples.

8) Over speed violation rate $R_s$

$$R_s = \frac{V_s}{V_t}$$  \hspace{1cm} (3)

$V_s$ is the number of annual speeding violations; $V_t$ is the total number of annual violations.

9) Violation rate of drunk driving $R_w$
10) Illegal parking violation rate $R_p$
11) Bad weather ratio $R_b$
12) Road horizontal visibility $l$

$$l = \frac{l_1 + l_2 + \cdots + l_n}{n}$$  \hspace{1cm} (4)

In the formula: $n$ is the number of samples; $l_1, l_2, \cdots, l_n$ refers to the horizontal visibility of $n$ samples, km.
3. Evaluation model based on hierarchical entropy

Analytic Hierarchy Process (AHP) [6] and Entropy Weight Method [7] have their advantages and disadvantages. In order to give full play to the advantages of the two methods and make the weight coefficients of the indicators conform to both objectivity and subjective considerations, an evaluation model of highway traffic safety based on Hierarchical Entropy was established.

3.1. Standardized Processing of Indicator Data

There are 12 secondary indicators in the index system. Most of the original data of these indicators differ greatly in value and dimension, so standardization processing was needed. The standardization processing of data in this paper adopted the “Min-max” standardization method.

3.2. Weight Coefficient Definition of Evaluation Index

When determining the weight coefficient of each evaluation index, the subjective weight of the evaluation index was determined by AHP method, and the objective weight of the evaluation index was determined by entropy method. The total weight coefficient of the evaluation index was determined by combining the two methods.

3.3. Evaluation Model Based on Hierarchical Entropy

The process of establishing the hierarchical entropy evaluation model is as follows:

Step 1: According to subjective weight $\alpha_f$ obtained by AHP method and objective weight $\omega_f$ obtained by entropy method, the comprehensive weight coefficient $\beta_f$ was determined as follows:

$$\beta_f = \frac{\alpha_f \omega_f}{\sum_{j=1}^{12} (\alpha_j \omega_j)}$$

(5)

Step 2: Establish a hierarchical entropy evaluation model for expressway traffic safety as follows:

$$\varphi_e = \sum_{f=1}^{12} \beta_f Y_{ef}$$

(6)

In the formula: $Y_{ef}$ is the value of the standard index value of the $f$ evaluation index in the $e$ year after the percentage system treatment; $\varphi_e$ is the assessed value in year $e$.

4. Evaluation model based on vector similarity

Based on the similarity of vectors [8], this paper described the quality of the evaluation object according to the vector relationship of the standardized data, evaluated the approaching degree between the evaluation object and the ideal value, and constructed a vector similarity evaluation model for expressway traffic safety. [9]

4.1. Vector Similarity

Vector similarity refers to the similarity between two vectors. Based on the distance between vectors $d$ and $\cos \theta$ of the angle between vectors, the similarity $\mu$ between vectors $a$ and $b$ is as follows:

$$\mu = \frac{\cos \theta}{1 + d}$$

(7)

4.2. Evaluation Model Based on Vector Similarity

Vector similarity degree of expressway traffic safety refers to the similarity degree between actual traffic safety condition and ideal value of expressway. If the traffic safety level of the evaluated object expressway has an ideal value, the proximity between the evaluation value and the ideal value in
different years of expressway reflects the quality of the performance index of the evaluated object, that is, the quality of expressway traffic safety. The steps of the evaluation model are as follows:

Step 1: Determine the standardized evaluation matrix of evaluation index. Suppose \( i = 1, 2, \ldots, n \) evaluation objects, \( j = 1, 2, \ldots, m \) indicators. After standardizing the indexes, the standardized evaluation matrix of expressway traffic safety is as follows:

\[
\mathbf{p}_{ij} = \begin{bmatrix}
p_{i1} & \cdots & p_{in}
\vdots & \ddots & \vdots
p_{i1} & \cdots & p_{im}
\end{bmatrix}
\] (8)

In the formula: \( p_{im} \) is the evaluation index value of item \( m \) in the \( n \)th year, and \( \mathbf{p}_{ij} \) is the standardized evaluation matrix of expressway traffic safety.

Step 2: Determine the weight coefficient of evaluation index. In order to determine the impact degree of each evaluation index in the evaluation, the weight coefficient of each evaluation index is determined by AHP method. The weight coefficient of evaluation index \( j \) is \( \alpha_j \).

Step 3: Compute the vector similarity of expressway traffic safety. The expressway traffic safety in the \( n \)th year is regarded as a vector, and the weighted evaluation object is recorded as \( \mathbf{A}_i \).

\[
\mathbf{A}_i = (\alpha_1 p_{i1}, \alpha_2 p_{i2}, \ldots, \alpha_m p_{im})^T
\] (9)

Assuming that the ideal value of evaluation is \( \mathbf{A}_0 \), the vector composed of the weight coefficient of the evaluation index of expressway traffic safety is assumed to be the ideal value.

\[
\mathbf{A}_0 = (\alpha_1, \alpha_2, \ldots, \alpha_m)^T
\] (10)

Then the distance between vectors and the angle cosine between vectors of expressway traffic safety are as follows.

\[
d_i = |\mathbf{A}_i - \mathbf{A}_0|
\] (11)

\[
\cos \theta_i = \frac{\mathbf{A}_i \cdot \mathbf{A}_0}{|\mathbf{A}_i| |\mathbf{A}_0|}
\] (12)

In formula: \( d_i \) is the distance between vector \( \mathbf{A}_i \) and vector \( \mathbf{A}_0 \); \( \theta_i \) is the angle between vector \( \mathbf{A}_i \) and vector \( \mathbf{A}_0 \).

Then the vector similarity between weighted evaluation object \( \mathbf{A}_i \) and ideal value \( \mathbf{A}_0 \) is as follows.

\[
\mu_i = \frac{\cos \theta_i}{1 + d_i}
\] (13)

In the formula, \( \mu_i \) is the vector similarity of expressway traffic safety.

Therefore, according to the vector similarity \( \mu_i \) of expressway traffic safety, we can judge the level of expressway traffic safety in each year, and rank the evaluation results.

5. Conclusion

1) Based on the traffic safety situation of expressway, considering the characteristics of human, vehicle, road, environment and accident, a traffic safety evaluation index system which is generally applicable to expressway is constructed. Among them, the evaluation index is hierarchical and quantifiable, and data processing is convenient.

2) The evaluation model based on hierarchical entropy and vector similarity are constructed. Both models start from subjective and objective aspects, which not only avoids the subjectivity of expert
evaluation, but also overcomes the excessive objectivity of data evaluation, and each model has its own emphasis.

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