Level-Fuzzy Comprehensive Evaluation Method of Urban Tunnel Traffic Safety

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Abstract **— With the continuous increase of the road mileage of Nanjing City, the traffic safety state, traffic operation status is getting more and more attention. The traffic safety state of urban road tunnel is scientifically evaluated, and the research on the relevant aspects is not very mature in China, but its importance is obvious. This study aims to establish a set of scientific evaluation system based on the tunnel traffic safety analysis according to the main factors affecting the traffic safety, in order to construct an evaluation system and relevant evaluation method specialized for urban road tunnel traffic safety to provide theoretical basis to improve the safety of tunnel traffic.**

Keywords - Urban Tunnel Traffic Safety, Level-Fuzzy Comprehensive Evaluation Method

I. INTRODUCTION

Urban road tunnel traffic safety evaluation and analysis is a scientific management for the tunnel and is important to maximize the economic efficiency of the tunnel operators. Use the evaluation system of urban road tunnel traffic safety to evaluate tunnels' traffic running status scientifically and comprehensively, and we can understand and detect traffic safety of the tunnel and provide a basis for tunnel decision and management.

The general idea and process of tunnel traffic safety evaluation is shown in Fig. (1).

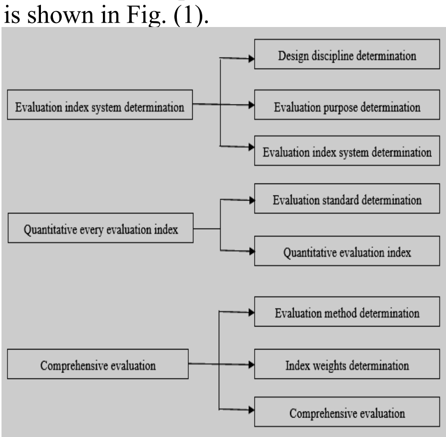

Figure 1. General idea of evaluation and flow chart

II. ESTABLISHMENT OF URBAN ROAD TUNNEL TRAFFIC SAFETY EVALUATION INDEX SYSTEM

In urban road tunnel traffic safety evaluation, the selection of evaluation index plays a crucial role in the establishment of evaluation system.

A. *Principle to establish evaluation system*

For comprehensive evaluation, we must first be able to select some comprehensive, scientific physical parameters which can reflect tunnel traffic safety, and the content involved in the traffic operating environment inside the tunnel are more complex, so we should follow the following principle to establish evaluation index system.

(1) Scientific principle

Selecting the evaluation index should ensure to reflect the traffic conditions of the tunnel 360-accurately, while ensuring that the formula and concepts used are accurate, and the sign of transport parameters should be in line with industry norms. Index selection should avoid duplication, and correctly reflect the relationship between the index and the overall on the basis of science.

(2) Objectivity principle

The selected indicators should be able to objectively reflect the traffic running status, while ensuring the accuracy of obtained data and the comprehensiveness and reliability of sources, and the evaluation method must secure its objective without subjective assumptions.

(3) Overall principles

The evaluation system established should be able to focus on the target system, and reflect all aspects of the system through all the features and its trends. Links between both indicators are related and independent, for the state of traffic safety is a complex system, it has to be able to reflect the characteristics of the traffic flow, but also reflect the wide range of circumstances in driver characteristics, tunnel environment and transport facilities to ensure the overall unity.

(4) Non-linear principle

The traffic safety evaluation of tunnel is not a simple linear problem, but is a more complex system problem, so it has to follow the non-linear principle to realize the optimization of index system architecture with a suitable method.

(5) Practical principle

Tunnel traffic safety evaluation study is to resolve the real problems in tunnel operation and management. Therefore, the index selection should be combined with practice, selecting common indicators in daily statistics or indicators readily available so as to visually analyze problems and lay the possible foundation for the subsequent countermeasures implementation.

B. Related establishment of evaluation system

1. Structure type of evaluation system

The common structure types of evaluation system mainly include the following three ways: unitary structure (Fig. (2)), linear structure (Fig. (3)), and tower structure (Fig. (4)).

Unitary structure is mainly used in the system of single index, and the index relations in linear structures are parallel. Tower structure has a clear level with top-down structure. According to the logic, you can drill down for more subordinate index. Tower structure is often used for comprehensive evaluation of some factors. This paper will preclude the use of AHP, and the most commonly used is the tower structure.

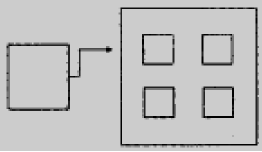

Figure 2. Unitary structure

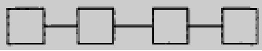

Figure 3. Linear structure

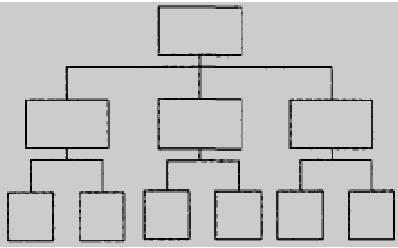

Figure 4. Tower structure

2. Basic analysis of evaluation index)

According to related literatures combined with the collected data and field investigation and analysis, from five aspects of traffic flow characteristics, driver characteristics, transport facilities, tunnels environment and other factors, the paper proposes some primary indicators of the following evaluation. Chapter 2 before has made a presentation of key concepts, here will just make a brief analysis.

(1) Traffic flow characteristics

Traffic flow characteristics is an important aspect of tunnel traffic safety evaluation. The quality of traffic flow conditions will directly affect the traffic safety status of the tunnel.

Traffic volume (pcu / h)

Traffic volume refers to the number of vehicles per unit time. The size of traffic volume will significantly affect traffic flow, thus affecting the speed of vehicles, so it is a more important indicator.

Average traffic speed (km / h)

Driving speed is an important indicator for the operation, management and control of the tunnel. Studies before have repeatedly analyzed the effect of speed on traffic safety. The tunnel entrance and speed has some differences. When conducting research, we should separately measure their speed and take the mean value. Tunnel generally has requirements of speed restriction with general speed limit about 80km/h within the tunnel, so the optimum operating speed should be 70-80km/h. The farther speed deviates from this range, the worse its traffic running status is.

Peak hour flow ratio (%)

Peak hour flow ratio is the ratio of peak hour traffic volume to the day traffic volume.

Headway of the car (S)

For traffic study, the larger headway of the car means better, and larger headway would ensure that there are an ideal pitch conducive to traffic safety between two vehicles.

Road capacity

Road capacity is an important indicator reflecting the load capacity of urban roads and road traffic planning often uses the relevant indicators.

Models constituting ratio (%)

Single traffic flow composition is a more ideal state, but in reality, the mixed phenomenon of large cars and small cars is more common, and its operation is also poor.

(2) Driver characteristics

Visual characteristics

When driving in a tunnel, the sun glare will directly affect the driver’s vision, and it takes some time to restore vision after glare disappears, which is very unfavorable for traffic safety.

Physiological characteristics

Tunnel has closed and small space, which is quite different from open-air road. It is easy to give the driver the feeling of discomfort with psychological state of tension, which will affect traffic safety.

Visibility

Under the impact of “white hole effect” and “black hole effect”, the driver’s visibility of traffic signs will be significantly reduced.

(3) Transport facilities

Pavement evaluation index (PQI)

Pavement evaluation uses PQI, PQI is calculated with the use of sub-index weighting, and its value range is 0-100. The greater the value is, the better the road conditions indicate.

$$PQI = PCI' \times P1 + RQI' \times P2 + SSI' \times P3 + SFC' \times P \quad (1)$$

Where, P1, P2, P3, P4 is the corresponding index weights.。

Road plane and linear

Generally road plane and linear often just meets regulatory requirements, if we can conduct more user-friendly design, it will be conducive to the tunnel ventilation and reduce other poor emission.

Traffic guidance signs

Reasonableness of traffic signs, visibility of traffic signs and height of traffic signs are closely related with tunnel traffic safety.

(4) Tunnel environment

Emissions concentration of CO, SO2, PM10

CO, SO2 and PM10 are some indicators used to measure the air quality inside the tunnel, where, CO is one of the main pollutants emissions from vehicles in the tunnel.

Illumination

Lighting conditions in the tunnel will directly affect the visual characteristics of the driver, and it is an important factor of traffic safety.

Noise

Motorized vehicle in tunnel is bound to generate noise, the size of the noise will affect the driver's physiological and psychological state, which should be paid attention on.

Pavement humidity

Pavement humidity is mainly used to reflect humid conditions inside the tunnel, which is closely linked to the adhesion coefficient of Road Street.

Temperature

The temperature inside the tunnel maintaining at 20-25 Celsius degrees is an ideal state. The farther the deviation range is, the less it is conducive to traffic safety.

(5) Other factors

Weather

Weather condition is difficult to quantify, so the weather usually use fuzzy method for evaluation.

Overloading

Overloaded of truck has been a huge security risk and should be valued.

3. Selection method of evaluation index

On the basis of adequate information gathering and literature research, the selection methods of evaluation index use theoretical analysis, expert consultation and satisfaction survey. Comprehensively considering, ultimately determine the required evaluation. Specific tunnel traffic safety evaluation index selection process is shown in Fig. (5).

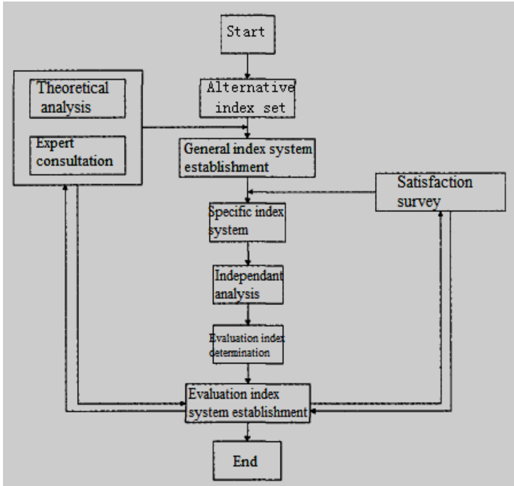

Figure 5. The flow chart of tunnel traffic safety evaluation index

4. Evaluation index system establishment

To make comprehensive evaluation of tunnel traffic safety, it will be analyzed from the perspective of various factors. The paper establishes the evaluation index system from five aspects of traffic flow characteristics, driver characteristics, transport facilities, tunnels environment and other factors in accordance with the principle of selecting indicators. Specific evaluation classification is seen in Table 1. By the method of AHP, it establishes a three-layer structure model of evaluation index system, as described in table 1. With this system, you can make comprehensive evaluation of tunnel traffic safety.

TABLE 1. THE EVALUATION CLASSIFICATION OF TUNNEL TRAFFIC SAFETY

Target layer(A)	**Criterion layer(B)**	**Index layer©**
Urban Road Tunnel Traffic Safety(A)	Traffic flow characteristics(B1)	Peak hour flow ratio (C11)
		Average traffic speed (C12)
		Headway of the car (C13)
		Models constituting ratio (C14)
	Driver Characteristics(B2)	Visual characteristics(C21)
		Physiological characteristics(C22)
		Visibility(C23)
	Transportation Facilities(B3)	Road conditions（C31）
		Road plane and linear(C32)
		Traffic guidance signs(C33)
	Tunnel environment(B4)	CO emissions(C41)
		Illumination(C42)
		Noise(C43)
		Pavement humidity(C44)
		Temperature(C45)
		PM10 Emissions(C46)
	Other factors(B5)	Weather(C51)
		Overloading（C52）

C. *Evaluation index calculation and evaluation criteria*

This paper divides the results into five grades, set evaluation grade be S, namely,

S = {□, □, □, □, □} = {good, better, general, poorer, poor}, □ level represents traffic safety in good condition, □ level indicates poor traffic safety status. Reference GB and related industry standards in road, the evaluation standard of tunnel traffic safety evaluation of quantitative and qualitative indicators is made, as shown in Table 2 and Table 3 below.

TABLE 2. EVALUATION STANDARD OF TUNNEL TRAFFIC SAFETY EVALUATION OF QUANTITATIVE

Reviews Ratings	**Poor**	**Poorer**	**General**	**Better**	**Good**
Rating Index	[0,60]	[60,70]	[70,80]	[80,90]	[90,100]
Peak hour flow ratio(%)	[12,15]	[10,12]	[8.5,10]	[7.5,8.5]	[3,7.5]
Average speed of vehicles(km/h)	[90,100]	[50,60]	[80,90]	[60,70]	[70,80]
Headway(S)	[0,5]	[5,8]	[8,10]	[10,13]	[13,20]
Proportion of carts(%)	[50,60]	[60,80]	[30,50]	[80,100]	[0,30]
Road conditions PQI	[0,40]	[40,55]	[55,70]	[70,85]	[85,100]
CO emissions(mg/m3)	[7.20]	[6,7]	[5,6]	[4,5]	[0,4]
Noise(dB)	[90,100]	[80,90]	[70,80]	[60,70]	[30,60]
Temperature(℃)	[-10,0]	[0,10]	[230]	[15,20]	[20,25]

TABLE 3. EVALUATING STANDARD OF TUNNEL TRAFFIC SAFETY EVALUATION OF QUALITATIVE

Reviews Ratings	**Poor**	**Poorer**	**General**	**Better**	**Good**
Rating Index	[0,60]	[60,70]	[70,80]	[80,90]	[90,100]
Visual characteristics	Seriously affected	Obviously affected	More significantly affected	Less affected	Almost have nothing with glare effects
Physiological and psychological characteristics	Great psychological pressure of driver	More intense and more pressure	A certain pressure	Less psychological stress	No psychological pressure, no physiological effect
Visibility	Great difficulties	No complete visibility	Basically identification	Slightly affected	Good visibility
Roads plane and linear	A more serious security risk	Significant traffic safety problems	Slightly affect driving	No influence on the traffic safety	Without risks
Reasonable traffic sign set	Seriously unreasonable	Obviously unreasonable	Somewhat unreasonable	reasonable	Good visibility
Illumination	Serious shortage of brightness	Obviously inadequate	Slightly less	Can basically meet the requirements	Bright, good line of sight
Pavement humidity	Too wet	Too dry	Wet	Dry	Moist
Weather Conditions	Bad weather	Worse weather	General weather	Better weather	Good weather
Overloading	Seriously overloaded	Obviously overloaded	Slightly overloaded	Almost no overload	Completely no overload

D. *Evaluation of the right to determine the method of weight*

For the weight of evaluation index, the paper uses analytic hierarchy process. Analytic Hierarchy Process (abbreviated AHP) is a qualitative, quantitative multi-criteria decision making method. Based on the actual needs, it divides the system into several hierarchical levels, and clear the subordinate relationship between factors. After the establishment of AHP model, make pairwise comparison in the elements of every layer, to establish judgment matrix and solve the weight vector. The general 1-9 scale and reciprocal scale method is shown in Table 4.

Table 4. Scale of judgment matrix and its meaning

No.	**Level of importance**	**Cij Assignment**
1	Elements i and j are equally important	1
2	Element i is slightly more important than element j	3
3	Element i is obviously more important than element j	5
4	Element i is strongly more important than element j	7
5	Element i is extremely more important than element j	9
6	Element j is slightly more important than element i	1/3
7	Element j is obviously more important than element i	1/5
8	Element j is strongly more important than element i	1/7
9	Element j is extremely more important than element i	1/9

Note: Cij={2, 4, 6, 8, 1/2, 1/4, 1/6, 1/8} represents the important rate between Cij={l, 3, 5, 7, 9, l/3, 1/5, 1/7, 1/9}.

Single-level sorting and consistency check. Consistency test indicators $CI = \frac{\lambda_{\max} - n}{n-1}$, when the random consistency ratio $CR = \frac{CI}{RI}$ <0.10, it can be considered that single-level sorting structure has satisfactory consistency. Otherwise, we need to adjust the values of the matrix elements. When making level analysis, finally it should make overall level sorting and consistency check.

III. RESEARCH ON TRAFFIC SAFETY ASSESSMENT METHODS OF URBAN ROAD TUNNEL

Common comprehensive evaluation methods are: expert, fuzzy comprehensive evaluation method, artificial neural network evaluation method, such level-fuzzy comprehensive evaluation method has the advantage of AHP and fuzzy mathematics. Taking fuzzy evaluation as the basic framework, using AHP to determine the weight is a more comprehensive evaluation method.

(1) Evaluation factors set determination

For a particular object, we should make relevant evaluation, it is necessary to filter out the main factors that reflect this phenomenon to form evaluation factors.

Assuming that the number of main influencing factors of this phenomenon is m, with u1, u2, …, um, the forming evaluation factors can be written as U = {u1, u2, ..., um}.

(2) Reviews set or evaluation grade set determination

For each factor, they can be given some comment or divided into several levels. If it is divided into m levels, with v1, v2, …, vm, and the evaluation grade set can be written as V = { v1, v2, …, vm}.

The paper divides evaluation grade into five levels of good, better, general, poorer, poor, respectively. Namely, the evaluation level set established is V = {good, better, general, poorer, poor}.

(3) Membership function determination

Membership is primarily used to characterize the fuzzy relationship between U and V, generally determined by membership function. Common membership functions are triangular and trapezoidal shape. Due to the simple membership function of triangle which is easy to calculate, the calculation result is not much different compared with other complex functions, therefore, it is applied more widely. In this paper, the smaller the better indicators mainly use linear triangular function and lower half trapezoidal distribution function, and the detailed characteristic curve is shown in Fig. (6).

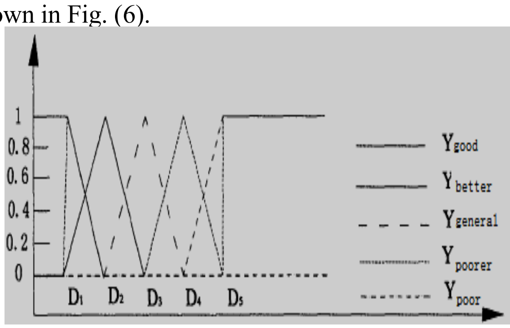

Figure 6. The membership function curve of fuzzy as small as possible indicators

Corresponding expressions of membership functions are as follows:

$$Y_{\text{good}}(x)=\begin{cases}1, x\le D_1\\ \dfrac{D_2-x}{D_2-D_1}, D_2<x<D_1\\ 0, x\ge D_2\end{cases}\quad (2)$$

$$Y_{\text{better}}(x)=\begin{cases}0, x<D_1 \text{ or } x\ge D_3\\ \dfrac{x-D_1}{D_2-D_1}, D_1\le x<D_2\\ \dfrac{D_3-x}{D_3-D_2}, D_2\le x<D_3\end{cases}\quad (3)$$

$$Y_{\text{general}}(x)=\begin{cases}0, x<D_2 \text{ or } x\ge D_4\\ \dfrac{x-D_2}{D_3-D_2}, D_2\le x<D_3\\ \dfrac{D_4-x}{D_4-D_3}, D_3\le x<D_4\end{cases}\quad (4)$$

$$Y_{\text{poorer}}(x)=\begin{cases}0, x<D_3 \text{ or } x\ge D_5\\ \dfrac{x-D_3}{D_4-D_3}, D_3\le x<D_4\\ \dfrac{D_5-x}{D_5-D_4}, D_2\le x<D_3\end{cases}\quad (5)$$

$$Y_{\text{poor}}(x)=\begin{cases}0, x\le D_4\\ \dfrac{x-D_4}{D_2-D_1}, D_4\le x<D_5\\ 1, x\ge D_5\end{cases}\quad (6)$$

The bigger the better indicators mainly use linear triangular function and liter half trapezoidal distribution function, and the detailed characteristic diagram is shown in Fig. (7).

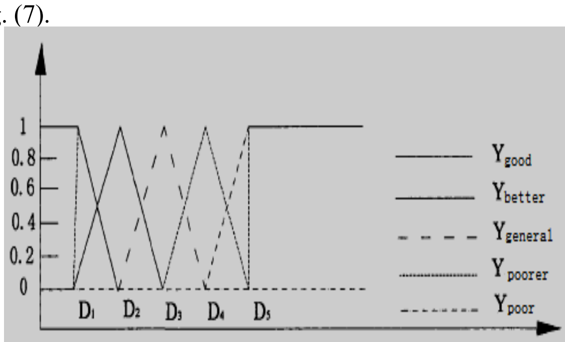

Figure 7. The curve of fuzzy membership function of better indicators

Corresponding expressions of membership functions are as follows:

$$Y_{\text{好}}(x)=\begin{cases}1, x\le D_1\\ \dfrac{x-D_2}{D_2-D_1}, D_2<x<D_1\\ 0, x\le D_2\end{cases}\quad (7)$$

$$Y_{\text{better}}(x)=\begin{cases}0, x<D_3 \text{ or } x\ge D_1\\ \dfrac{D_1-x}{D_1-D_2}, D_2\le x<D_1\\ \dfrac{x-D_3}{D_2-D_3}, D_3\le x<D_2\end{cases}\quad (8)$$

$$Y_{\text{general}}(x)=\begin{cases}0,\ x<D_4\ \text{ or }\ x\geq D_2\\ \dfrac{D_2-x}{D_2-D_3},D_3\leq x<D_2\\ \dfrac{x-D_4}{D_3-D_4},D_4\leq x<D_3\end{cases}\quad(9)$$

$$Y_{\text{poorer}}(x)=\begin{cases}0,\ x<D_5\ \text{ or }\ x\geq D_3\\ \dfrac{D_3-x}{D_3-D_4},D_4\leq x<D_3\\ \dfrac{x-D_5}{D_4-D_5},D_5\leq x<D_4\end{cases}\quad(10)$$

$$Y_{\text{poor}}(x)=\begin{cases}0,\ x\geq D_4\\ \dfrac{D_4-x}{D_4-D_5},D_5\leq x<D_4\\ 1,\ x<D_5\end{cases}\quad(11)$$

Through the above formulas, you can get the membership rij of various factors ui(i=l, 2, ..., m) for the evaluation level vj(j=l, 2, ..., n), and the univariate evaluation result for the i-th factor is:

ri= (ri1, ri2,…, ri1)

In order to be analyzed, generally, rij>0 and make normalization of ri, so that $\sum_{j=1}^{n} r_{ij}=1$

(4) Evaluation matrix establishment

For the m factors, after a single factor rating, take the result ri as the i-th row to form an integrated fuzzy matrix R, which contains n evaluation levels of m factors.

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n}\\ r_{21} & r_{22} & \cdots & r_{2n}\\ \vdots & \vdots & \cdots & \vdots\\ r_{m1} & r_{m2} & \cdots & r_{mn}\end{bmatrix}$$

(5) Weight vector determination

Determining the weights has subjective weighting of expert method and objective weighting method, and this paper uses AHP to determine weights. If you set the weight of influence factor ui as wi, the corresponding weight vector of influence factors set U can be expressed as: W=(w1, w2, …, wm). For the weight wi, require wi≥0 and Σwi=1.

(6) Fuzzy synthesis

After determining the fuzzy matrix R and weight vector W, take weight vector W for fuzzy synthesis of matrix R, and the overall degree of membership can be obtained for evaluated object of each evaluation level.

Set fuzzy comprehensive evaluation results S=(s1, s2, …, sn), then

S = W°R (12)

Where, ° means fuzzy operator symbol, and the common operator symbol has Zadeh operator, the weighted average operator, the Mahayana product operator and bounded operator and so on.

After selecting fuzzy operator to calculate S, we also need to normalize S so that Σsj= 1.

(7) Making decisions

For the final fuzzy evaluation result S=(s1, s2, …, sn), sj denotes the membership degree for evaluated object of evaluation level vj. Where, the value corresponding to the maximum level represents that the evaluated object is good for that grade, and this level is the evaluated result.

For example, the evaluation results S = {0.22, 0.38, 0.18, 0.11, 0.11}, indicating that the evaluation measure of "good" is 0.22, the "better" evaluation measure is 0.38. According to the maximum membership principle, 0.38 is the maximum, therefore, the evaluated object belongs to the "better" level, and the evaluation level is the results of the evaluation.

IV. CONCLUSION

On the basis of traffic safety analysis of the tunnel, this paper establishes a relatively complete and scientific evaluation system according to the main factors of traffic safety, and introduces the level-fuzzy comprehensive evaluation method, which makes theoretical basis for application research of relevant examples in the future.

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