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Tunnel Traffic Safety Evaluation Based on Uncertain Measure Theory

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Abstract

In order to evaluate the operational safety of highway tunnels, a highway tunnel safety evaluation model is established based on the unassured measurement theory. First, 11 indicators were selected from 4 aspects of safety facilities, traffic flow, climate environment, and road conditions to establish the evaluation system and standards; based on the field survey data and historical data, the unknown measurement function of each indicator was established. Finally, through the verification of a highway tunnel in Chongqing. The results show that the established unascertained measurement model can truly and accurately evaluate the safety of highway tunnels, indicating that this method is feasible and can be popularized and applied in practical engineering.

Keywords

Highway Tunnels; Safety Evaluation; Uncertain Measure Theory; Traffic safety.

1. INTRODUCTION

With the rapid development of my country's economy, the road mileage is increasing. Tunnels have the characteristics of overcoming elevation and improving alignment standards in highway construction, so they are widely used in high-grade highways. According to the "Statistical Bulletin on the Development of the Transportation Industry" issued by the Ministry of Transport, by the end of 2020, there were 21,316 highway tunnels and 21,999,300 linear meters across the country [1].

Tunnels, as special sections on highways, not only provide convenience to people, but also increase the safety risks of the sections. Studies have shown that, compared with ordinary roads, tunnels are the bottleneck sections of expressways. Compared with ordinary roads, the total number of accidents in highway tunnels is relatively small, but the consequences and impacts are often greater [2]. At the same time, statistics show that the number of traffic accidents per kilometer in the tunnel is significantly higher than that of other normal road sections, and the number of traffic accidents per kilometer is second only to bridges in all types of road sections [3]. In addition, there are also many problems in the current tunnel operation, such as aging safety facilities, large damage to the road surface, etc., which affect the driving safety of the tunnel. Therefore, it is necessary to evaluate the safety of highway tunnels, determine the safety level of the tunnel, find out the existing safety hazards and improve them, so as to improve the safety of the tunnel.

Domestic scholars have used a variety of models for safety evaluation. Based on the fuzzy comprehensive analysis method, Liu Hongtao [4] established a safety operation evaluation system considering three categories of structural safety, environmental safety, and safe operation, and quantified the evaluation results. The safety management level belongs to a relatively safe level, which is consistent with the actual situation. Xue Feng [5] proposed a

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combined evaluation method based on AHP-DEMATEL and cloud model, which can overcome the evaluation error caused by interference factors, overcome the ambiguity between indicators, and make the evaluation results more intuitive. He Yulong [6] constructed a model based on the undetermined measure theory and applied it to the study of highway traffic safety evaluation. The results show that the model can accurately evaluate the danger level of highway sections, and roughly reflect the safety level of vehicles on the highway. Comprehensive situation. Yang Chunfeng [7] put forward the concept of the theoretical traffic safety degree of expressway, and used the grey relational method to determine the influence weight of each factor. Through example verification, it shows that the theoretical traffic safety degree can reflect whether there are safety hazards on the expressway.

On the basis of the existing research, this paper establishes an unascertained measurement theoretical evaluation model for tunnels from four aspects: safety facilities, traffic flow, climate environment, and road conditions. This model is used to scientifically, rationally and objectively evaluate a highway tunnel in Chongqing, thereby improving the safety level of highway tunnel operation.

2. PROPERTIES

Suppose there are R evaluation objects n, and the evaluation object space is $R=\{R_1,R_2,\cdots,R_n\}$, R_i represents the i-th evaluation object; Let the evaluation index set be $X=\{X_1,X_2,\cdots,X_m\}$, X_j represents the j th evaluation index; Record the evaluation space set as $U=\{U_1,U_2,\cdots,U_p\}$, where U_k represents the k-th evaluation level. If the k th rating is better than the $k+1$ th rating, denoted as $U_k > U_{k+1}$. When $U_1 > U_2 > \cdots > U_p$, consider $U_1 > U_2 > \cdots > U_p$ to be an ordered segmentation class on the set of levels to be evaluated.

2.1. Unascertained Measure of Single Index

Definition $\mu_{ijk}=\mu\left(R\in U_k\right)$, represents the degree to which the i-th evaluation object belongs to the k-th evaluation level U_k with regard to the j-th evaluation index, referred to as Measure, and the requirements are met:

$$0 \le \mu\left(x_{ij} \in U_k\right) \le 1 \tag{1}$$

$$\mu\left(x_{ij} \in U\right) = 1 \tag{2}$$

$$\mu\left[x_{ij} \in \bigcup_{i=1}^{k} U_i\right] = \sum_{i=1}^{k} \mu(x_{ij} \in U_i) \tag{3}$$

Formula (2) is normality, and formula (3) is additivity. If the measure does not satisfy these two properties, the value is considered theoretically unreliable.

Defining matrix $(\mu_{ijk})_{m\times p}$ as a single index measurement matrix, there are:

$$\left(\mu_{ijk}\right)_{m\times p}=\begin{bmatrix}\mu_{i11} & \mu_{i12} & \cdots & \mu_{i1p}\\ \mu_{i21} & \mu_{i22} & \cdots & \mu_{i2p}\\ \vdots & \vdots & \ddots & \vdots\\ \mu_{im1} & \mu_{im2} & \cdots & \mu_{imp}\end{bmatrix} \tag{4}$$

2.2. Determination of the Weight of A Single Indicator

Let w_{ij} represent the relative importance of index X_j compared to other indexes, require w_j satisfies $0\le w_j\le 1$, and $\sum_{j=1}^{m} w_j=1$, let w_j be the weight of X_j, $w=\{w_1,w_2,\cdots,w_m\}$, w is called the index weight vector. In the unascertained measure model, the information entropy method is commonly used to determine the weight, and the calculation formula is as follows:

$$v_j=1+\frac{1}{\lg p}\sum_{i=1}^{p}\mu_{ij}\times\lg\mu_{ij} \tag{5}$$

$$w_j=v_j\Big/\sum_{i=1}^{n}v_j \tag{6}$$

2.3. Multi-index Comprehensive Measurement Evaluation Vector

Assume:

$$\mu_{ik}=\sum_{j=1}^{m}w_j\mu_{ijk}\left(i=1,2,\cdots n;k=1,2,\cdots,p\right) \tag{7}$$

Obviously, $0\le\mu_{ik}\le 1$ and $\sum_{k=1}^{m}\mu_{ik}=1$, the μ_{ik} determined by formula (7) is the unascertained measure.

2.4. Confidence Recognition

Let λ be the confidence level (and usually λ=0.5 or 0.7), let:

$$k_0=\min\left\{k:\sum_{i=1}^{k}\mu_i\ge\lambda,\left(k=1,2,\cdots,p\right)\right\} \tag{8}$$

It is considered that the sample to be evaluated belongs to the evaluation level.

3. HIGHWAY TRAFFIC SAFETY EVALUATION SYSTEM

According to the relevant high-level highway safety evaluation index system, the following factors are finally selected from the four aspects of safety facility index, traffic flow index, climate environment index and road condition index: traffic monitoring facilities (X1), ventilation and lighting control Facilities (X2), central control and management facilities (X3), fire protection and evacuation facilities (X4), V/C (X5), average operating speed difference (X6), line of sight (X7), CO concentration (X8), annual failure The weather days (X9), the road surface condition index (X10) and the degree of anti-skidding of the road surface (X11), a total of 11 factors, are used as evaluation indicators.

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According to the data of on-site investigation and the relevant information collected, assign values to each indicator. Traffic monitoring facilities, traffic monitoring facilities, central control and management facilities, fire protection and refuge facilities, and pavement anti-skid coefficient are qualitative indicators, which are scored by experts. The scoring criteria are: excellent (85~100), good (70~85), Average (50~70), poor (0~50). The safety level of the road is divided into four levels, namely I, II, III and IV, which represent low risk, low risk, general risk and high risk respectively. The grading standard of each index is shown in Table I.

Table 1. Highway Traffic Safety Evaluation Index and Grading Standard

Evaluation elements	**Evaluation elements**	**unit**	**Evaluation level**			
			Class I	Class II	Class III	Class IV
safety facility index	Traffic Monitoring Facilities	-	excellent	good	generally	Poor
	Ventilation and Lighting Controls	-	excellent	good	generally	Poor
	Central control management facility	-	excellent	good	generally	Poor
	Fire and Evacuation Facilities	-	excellent	good	generally	Poor
traffic flow indicator	V/C	-	<0.35	0.35~0.55	0.55~0.75	>0.75
	Average running speed difference	km/h	<10	10~20	20~30	>30
Climate and Environmental	sight distance	m	>160	110~160	75~110	<75
	CO concentration	cm3/m3	<50	50~100	100~150	>150
	Bad weather days per year	d	<10	10~25	25~40	>40
road condition	Pavement Condition Index	-	>90	80~90	70~80	<70
	Slip resistance of pavement	-	excellent	good	generally	Poor

4. EXAMPLE APPLICATION

Take a road tunnel in Chongqing as an example to verify. The tunnel has a total length of 2.56km and a design speed of 80km/h. The relevant parameters obtained according to expert scoring and field measurement are shown in Table 2.

Table 2. Your table here and center

Evaluation samples	**Evaluation indicators**										
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
R1	82	75	79	87	0.56	17	140	109	27	85	78

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4.1. Constructing A Single-index Undetermined Measure Matrix

According to the definition of the unknown measure function and the evaluation grading and value of each evaluation index in Tables 1 and 2, establish traffic monitoring facilities, ventilation and lighting control facilities, central control and management facilities, fire protection and refuge facilities, V/C, average Figure 1 shows the single-index measurement functions of running speed difference, sight distance, CO concentration, annual number of days with bad weather, pavement condition index, and pavement skid resistance.

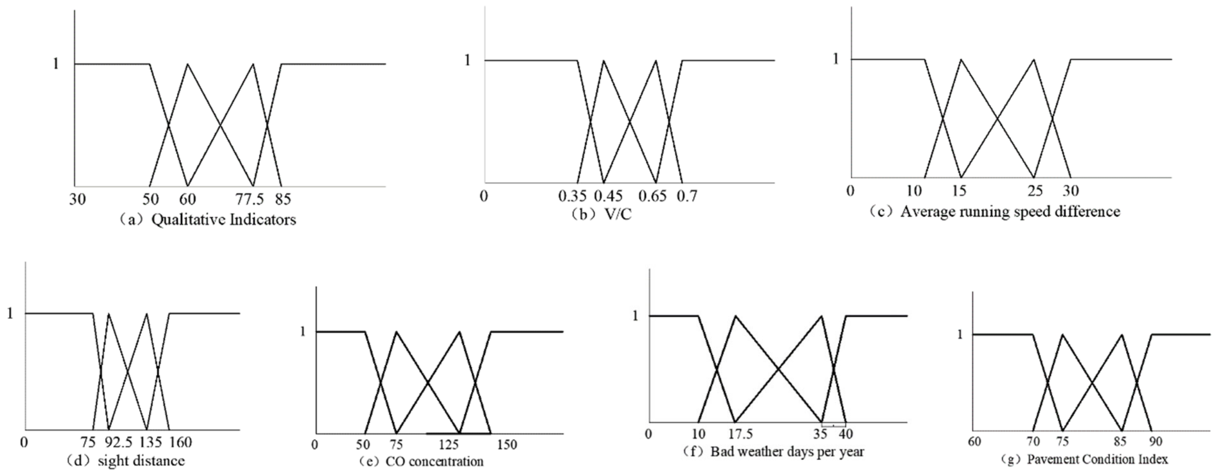

Figure 1. Undetermined measure function for a single indicator

4.2. Build A Single-index Measure Matrix

Substituting the values of each evaluation index in Table 2 into the above single-index measure function, the single-index unascertained measure matrix can be obtained as follows:

$$\left(\mu_{ij}\right)_{11\times4}=\begin{bmatrix} 0.6 & 0.4 & 0 & 0 \\ 0 & 0.86 & 0.14 & 0 \\ 0.2 & 0.8 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0.55 & 0.45 & 0 \\ 0 & 0.8 & 0.2 & 0 \\ 0.2 & 0.8 & 0 & 0 \\ 0 & 0.32 & 0.78 & 0 \\ 0 & 0.54 & 0.46 & 0 \\ 0 & 1 & 0 & 0 \\ 0.07 & 0.93 & 0 & 0 \end{bmatrix}$$

4.3. Calculate the Multi-index Measure Evaluation Matrix

Calculate the weight of the evaluation index by formulas (5)~(6), and the obtained weight of the evaluation index is (0.068,0.094,0.085,0.132,0.067,0.085,0.085,0.079,0.066,0.132,0.108).

According to formulas (5), (6) and (7), the multi-index comprehensive measure evaluation vector is obtained as:

$U=\left(0.2144,0.6412,0.1522,0\right)$

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4.4. Confidence Identification and Evaluation

Take the confidence $\lambda = 0.5$, Calculate the evaluation value of the comprehensive measurement evaluation value from large to small, $k_0 = 0.8556 > 0.5$, That is, the risk level of R_1 is Class I; Calculate the evaluation value of the multi-index comprehensive measurement evaluation value from small to large $k_0 = 0 + 0.1522 + 0.6412 > 0.5$. The risk level of R_1 is still level I, and the judgment is consistent before and after, so it can be judged that the safety level of the road tunnel R_1 is level II, that is, the safety level is a lower risk level, which is also consistent with the historical accident data of the tunnel. It shows that the tunnel can basically ensure safety during operation, but there are still some areas that can be improved.

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5. CONCLUSION

This paper establishes a road tunnel safety evaluation model based on the unascertained measurement theory, selects 11 indicators from four aspects of safety facilities, traffic flow, climate environment, and road conditions, and establishes a tunnel safety evaluation system. Using this model to evaluate the safety of tunnel operation Evaluation and analysis were carried out. The results show that the model can more realistically reflect the actual situation of highway tunnel operation, which is consistent with the actual situation, and at the same time, it is helpful for managers to find out the weak links in tunnel safety management, so as to improve the tunnel safety level.

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