FUZZY EVALUATING METHOD TO DISTINGUISH THE BLACK SPOT OF THE ROAD

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Abstract

When we improve the level of road traffic safety, it is critical and important to identify Black Spots. When the road section and intersections have great difference in road condition and traffic condition, the precision of identification can't be assured by old methods. And based on the fuzziness of traffic safety, the variety of the thinking means and the characteristic that is difficult to express the result of identification by the spoken language, the fuzzy evaluating method is set up. The method overcomes the shortcoming that the indexes are only single and the problems are not generally considered in the accident frequency method, the risk rate method, the matrix method and the quality control method. Except this, the fuzzy character of the safety evaluation is considered and it does not need to change the critical value frequently, so it is more convenient to apply than the critical value method. By analysis and comparison, the indexes that the method adopts include the mortality rate of a hundred million vehicles per kilometer, the mortality rate of ten thousand vehicles, the equivalent accident number of ten thousand vehicles and the ponderance index of safety. These indexes have the characteristic of relativity, representation and mensurability, so they can generally reflect the dividing result. According to these, a fuzzy mathematics mode is shown and it takes the example of road section and intersection to identify in Harbin City.

Key words: fuzzy vector; membership function; evaluation   Black Spot

Introduction

Accident-prone location, also called Black Spot, means the road section or intersection where traffic accident is outstanding. The first and most critical step of improving road traffic security is to determine the locations of the road sections and intersections that need urgent improving, so as to prioritize the order of importance and urgency, and adopt reasonable measures to enhance road traffic security level.

Black Spots not only reduce the service quality of the road seriously, but also increase the proportion of the cumulative number of accidents in the total number of accidents. According to the above-mentioned two points, identifying Black Spots, analyzing the reason why accidents occur frequently, and then putting forward homologous countermeasures, are economical and effective ways to improve road traffic safety condition. It is rather meaningful to firstly improve of the safety condition of Black Spots, especially under the condition of fund shortage [1].

When identifying Black Spots domestically and abroad, these methods are usually adopted:(1) Accident frequent method;(2) Risk rate method; (3) Matrix method;(4) Equivalent total accident number method;(5) Quality control method;(6) Critical rate method .In 1997, J. S. CHEN and S. C. WANG summed up the merits and faults of each method above and put forward the critical rate method for identifying dangerous road section. This method selects the maximum accident rate that road users can bear as the critical rate firstly, and then the minimum accident rate for any road section is given for different critical rate on the grounds of the significance level. The road where the accident rate exceeds the critical rate is considered as Black Spot. This method is superior to anyone above, because it considers the significant characteristics of Black Spot (including seriousness of accident, traffic volume, and length of road section) as a unity. Meanwhile, it can determine the priority order for improving Black Spots by choosing different danger rate. But, critical rates change with the development of economy and the enhancement of living standard. So, the departments concerned should update the database in time, in order to choose proper critical rate according to the circumstance of traffic accident and road improvement fund [2][3].

It can be seen from the analysis above that although various methods can set out from different angle to identify Black Spots, they may neglect some conditions (such as traffic volume, road condition, and seriousness of accident etc.) in actual application, decreasing the accuracy of the results. Therefore, various methods are all subjected to specific application condition restrictions. Even when identifying Black Spots that meet the application demand, the methods should also be studied, in order to raise the precision of results.

When the road section or intersection being identified has great difference in road condition and traffic condition, the precision of identification cannot be guaranteed by accident frequency method, risk rate method, matrix method, or quality control method .So it is not only necessary but also reasonable to establish a fuzzy evaluating model aiming at the fuzziness of traffic safety, the variety of the thinking means, and the characteristic that is difficult to express the result of identification by spoken language.

Mathematical model

The spirit of the fuzzy evaluating method is to establish mathematical model adopting principles of fuzzy mathematics [4][5] according to the fuzziness characteristic of the object studied.

Given a limited set Q as:

$$Q = \{q_1, q_2, \Lambda\ , q_n\} \tag{1}$$

where the member q_i (i=1 2 ... n)of Q denote evaluation object.

Given a limited collection K as:

$$K = \{k_1, k_2, \Lambda\ , k_m\} \tag{2}$$

where the member k_j (j=1 2 ... m)of K denote different evaluation indexes.

Let u_j be membership function of $k_j \in K$ that is the jth evaluation index, that is:

$$u_j = \mu(k_i) \qquad u_j \in [0,1] \tag{3}$$

Then make a limited fuzzy subset U, that is:

$$U = \{u_1, u_2, \Lambda\ , u_m\} \tag{4}$$

So it is necessary to search a fuzzy set B and make B meet the demand that:

$$B = \{b_1, b_2, \Lambda\ , b_n\} \qquad b_i \in [0,1] \tag{5}$$

Where member b_i of B denotes comprehensive evaluation index of the ith evaluation object.

As membership function u_j applies to all evaluation objects, so an evaluation matrix R, called fuzzy matrix, is obtained, that is:

$$R: Q \times U \rightarrow [0,1]$$

$$R = \begin{bmatrix} R_1 \\ R_2 \\ M \\ R_n \end{bmatrix} = \begin{bmatrix} r_{11} \ r_{12} \ \Lambda \ r_{1m} \\ r_{21} \ r_{22} \ \Lambda \ r_{2m} \\ M M M M M \\ r_{n1} \ r_{n2} \ \Lambda \ r_{nm} \end{bmatrix}_{n \times m} \tag{6}$$

Where $r_{ij} = R(q_i u_j) \in [0,1]$ denotes a membership grade of the ith evaluation object about the jth evaluation index [6].

Define S as the first level of evaluation space, and give a fuzzy vector A:

$$A = \begin{bmatrix} a_1 \\ a_2 \\ M \\ a_m \end{bmatrix} \tag{7}$$

Where a_j denote relative importance of each evaluation index about the first level of evaluation.

The first level of evaluation model is:

$$D = R \otimes A \tag{8}$$

Its extended form is:

$$\begin{bmatrix} D(q_1) \\ D(q_2) \\ M \\ D(q_n) \end{bmatrix} = \begin{bmatrix} r_{11} \ r_{12} \ \Lambda \ r_{1m} \\ r_{21} \ r_{22} \ \Lambda \ r_{2m} \\ M \ M \ M \ M \ M \\ r_{n1} \ r_{n2} \ \Lambda \ r_{nm} \end{bmatrix} \otimes \begin{bmatrix} a_1 \\ a_2 \\ M \\ a_m \end{bmatrix}$$

$$\begin{bmatrix} D(q_1) \\ D(q_2) \\ M \\ D(q_n) \end{bmatrix} = \begin{bmatrix} (r_{11} \wedge * a_1) \vee * (r_{12} \wedge * a_2) \vee * \Lambda \ \vee * (r_{1m} \wedge * a_m) \\ (r_{21} \wedge * a_1) \vee * (r_{22} \wedge * a_2) \vee * \Lambda \ \vee * (r_{2m} \wedge * a_m) \\ M \qquad\qquad M \\ (r_{n1} \wedge * a_1) \vee * (r_{n2} \wedge * a_2) \vee * \Lambda \ \vee * (r_{nm} \wedge * a_m) \end{bmatrix}$$

Where $\wedge *$¡¢$\vee *$ denote general fuzzy operator, it is marked as ($\wedge$£¬)¡¢($\vee$£¬), etc[7].

If we import many operators simultaneously, then each evaluation object can get a new fuzzy subset:

$$U_1 = \{D_1, D_2, \Lambda, D_p\} \qquad U_1 \in [0,1] \tag{9}$$

Where p denotes the number of fuzzy operators.

A new fuzzy relation can be obtained from Q and U1, that is:

$$R_1 : Q \times U_1 \rightarrow [0,1]$$

$$R_1 = \begin{bmatrix} d_{11} \ d_{12} \ \Lambda \ d_{1p} \\ d_{21} \ d_{22} \ \Lambda \ d_{2p} \\ M \quad M \quad M \quad M \\ d_{n1} \ d_{n2} \ \Lambda \ d_{np} \end{bmatrix} \tag{10}$$

Where d_{ik} denotes the evaluation value of Level One of the ith evaluation object calculated by formula (6) while adopting the kth fuzzy operator.

Then we obtain the second level of valuation $S_1 = (Q, U_1, R_1)$

In order to decrease subjectivity while determining whether $a_i \in A$, the second level of evaluation should be made in S1. Give a fuzzy vector G as:

$$G = (g_1, g_2, \Lambda\ , g_p) \tag{11}$$

Where the member g_k of G denotes the weight of the kth fuzzy operator related to the second level of evaluation, and:

$$\sum_{k=1}^{p} g_k = 1 \qquad g_k \in [0,1] \tag{12}$$

Then we obtain the second level of evaluation model :

$$B = G \times R_1^T = \{b_1, b_2, \Lambda\ , b_n\} \tag{13}$$

Where b_i denotes comprehensive evaluation index of the ith evaluation object, and:

$$b_i = \sum_{k=1}^{p} g_k d_{ik} \tag{14}$$

It is obvious that, the mathematical model above is the evaluation model of two levels, whose final result is a set of comprehensive evaluation indexes. If the membership function is inversely proportional to the value of evaluation index, then the bigger b_i is, the safer the road traffic is. So the traffic safety condition of the evaluation object is sorted according to the relative value of $b_i \in B$ [8].

Evaluation index

The right choice of evaluation index is a key upon which success or failure of evaluation model depends. Sifting the evaluation index should follow the principle of comparability, typicality and mensurability to assure the validity of the evaluation model. Four statistical indexes[9][10]—the accident number, the mortality number, the injury number and the economic losses are generally used while evaluating the level of traffic safety. Economic losses should be excluded when establishing evaluation model, because they are lack of comparability. Only direct economic losses are calculated, while indirect economic losses are much bigger. Generally, accident number, mortality number, injury number are recorded in details while recording road traffic accident, so they can be taken as the indexes of evaluation model. But, using directly the absolute value of the three indexes to carry on clustering comparison is obviously unreasonable, because of the great differences between road sections and intersections, so relative value should be adopted and reference indexes should be associated with the accident number, the mortality number and the injury number. Generally speaking, to construct relative indexes of the accident number, the mortality number and the injury number, length of road and road traffic volume can be adopted for the road sections as reference indexes, and the total volume of entrance for intersections. The description of each relative index selected is as follows:

1. The mortality rate of a hundred million vehicles per kilometer.

The mortality rate of a hundred million vehicles per kilometer is often used and is recognized as the most cogent of the multitude indexes that describe traffic safety level. In our country, there are no statistics of the vehicle-kilometer, and statistics for calculating vehicle fuel consumption per kilometer are not complete either, but the product of traffic volume during the statistical period and lengths of road section can replace the vehicle-kilometer.

2. Ponderance index of collision

There is no uniform definition of ponderance index of collision presently. This text uses the injury number to divide mortality number to get ponderance index of collision. The lower the value of this index is, the lower the seriousness of the accident is.

3. .The mortality rate of ten thousand vehicles

Originally, the mortality rate of ten thousand vehicles means the ratio of ten thousand times of the mortality of road traffic collisions to the number of local motor vehicles in a country or region. In this paper, it is defined as the ratio of ten thousand times of the mortality of road traffic collisions to the traffic volume in the road section or intersection, and it is taken as one of the evaluation indexes.

4. The equivalent accident rate of ten thousand vehicles

The equivalent accident number is the sun of equivalent accident number and accident number. Equivalent number is transformed from mortality number and injury number according to specific weight coefficients. The calculation method of the equivalent accident number of ten thousand vehicles is similar with that of the mortality rate of ten thousand vehicles.

Through the analysis above, it can be concluded that, for road sections, the mortality rate of a hundred million vehicles per kilometer, the mortality rate of ten thousand vehicles, the equivalent accident rate of ten thousand vehicles, and the ponderance index of safety can be selected to make up the set of evaluation indexes, while for intersections, the mortality rate of ten thousand vehicles, the equivalent accident rate of ten thousand vehicles, and the ponderance index of safety can be selected, that is:

$$K = \{k_1, k_2, k_3, k_4\} \qquad (15)$$

$$k_1 = \frac{F}{QL} \times 10^8 \qquad k_2 = \frac{F}{Q} \times 10^4 \qquad k_3 = \frac{ETAN}{Q} \times 10^4 \qquad k_4 = \frac{F}{J}$$

Where F denotes the number of mortality;

Q denotes two-way traffic volume for road section or the total volume of entrance for intersections;

L denotes the length of the road;

ETAN denotes the equivalent accident number of road section;

$$ETAN = TAN + 9.5F + 3.5J \qquad (16)$$

TAN denotes the accident number of road section (or intersection);

J denotes the injury number

k_j denotes relative index

The method proposed by this text overcomes the shortcomings of the accident frequent method, the risk rate method, the matrix method, and the quality control method, that the indexes are single and the problems are not generally considered. Except this, the fuzzy character of the safety evaluation is considered and it needn't change the critical value frequently, so it is more convenient to apply than the critical value method.

The validation of the membership function

When identifying Black Spots, the function of the membership function is not only that each index is converted into dimensionless value, but also the value of the membership function itself reflects the traffic safety level. The method below shows how to determine the membership function of each index, and it takes the example of the identification of Black Spots on road sections in Harbin. Intersections can use similar methods to validate the membership function of each index. In order to validate membership functions, some assumptions [11][12] are made in this paper.

Hypothesis 1

The membership function of the evaluation index k_j (j=1,2,3,4) has the following property:

$$u_j \in [0,1]$$

u_j =1 when $k_j \le c_j$ $u_j \to 0$ when $k_j \to +\infty$ Thus, the membership function can be expressed as follows:

$$u_j = \mu(k_j) = \begin{cases} 1 & k_j \le c_j \\ \dfrac{1}{1+[a_j(k_j - c_j)]^{b_j}} & k_j > c_j \end{cases} \quad \forall a_j, b_j, c_j > 0 \tag{17}$$

Hypothesis 2

Each evaluation index k_j could be considered a linguistic variable, whose value is a limited set V:

$$V = \{v_1, v_2, v_3, v_4\} = \{excellent, good, middle, bad\} \tag{18}$$

The road section is identified as black spot when $v_i = v_4$.

Hypothesis 3

Each member of V correspond to a possible distribution region of the membership function:

$\mu_j \in [0.00, 0.40]$ when $v_i = v_4$

$\mu_j \in (0.40, 0.65]$ when $v_i = v_3$

$\mu_j \in (0.65, 0.85]$ when $v_i = v_2$

$\mu_j \in (0.85, 1.00]$ when $v_i = v_1$

Therefore, there must be a set of critical values $k_{jl} (l = 1, 2, 3, 4)$ in the $k_j - u_j$ coordinate, namely:

$$\mu(k_{j1}) = \mu(c_j) = 1.00,\ \mu(k_{j2}) = 0.85, \mu(k_{j3}) = 0.65, \mu(k_{j4}) = 0.40$$

Through correlative investigation, each index could be calculated using fuzzy statistics method, and parameters of the membership functions can be determined by regression analysis.

The determination of fuzzy vector A and G

The determination of fuzzy vector A

The concept of the fuzzy vector A varies with the fuzzy operator adopted. This section adopts three fuzzy operators, matching each fuzzy operator. The physical meaning [14] of A is discussed in the following part.

(1) Fuzzy operator $(\wedge,\vee)$

The operation rule of the this fuzzy operator is

$$R(\wedge,\vee)A = \bigvee_{j=1}^{m}(r_{ij} \wedge a_j) \quad (19)$$

It is obvious that, the membership grade r_{ij} of the ith evaluation object about the jth evaluation index is corrected as $r_{ij}*$ by Formula (20):

$$r_{ij}* = r_{ij} \wedge a_j \quad (20)$$

So, a_j is the upper limit of $r_{ij}*$,that is a_j stands for the supreme persuasion that can be reached when the macro-evaluation result of the ith evaluation object is described by k_j only, obviously:

$$\sum_{j=1}^{m} a_j \neq 1 \qquad \forall a_j \in [0,1]$$

(2) Fuzzy operator $(\cdot,\vee)$

In this fuzzy operator a_j has the same meaning with the last operator, the only difference is that r_{ij} is achieved by multiplying rather than taking minimum value, that is:

$$r_{ij}* = r_{ij} a_j \quad (21)$$

(3) Fuzzy operator $(\cdot,+)$

In this operator, a_j denotes relative importance of each index (weight) when all evaluation indexes are considered simultaneously. So, in this operator, there is relation as follows:

$$\sum_{j=1}^{m} a_j = 1 \qquad \forall a_j \in [0,1] \quad (22)$$

Analysis above shows that A can be divided into two fuzzy subset $\tilde{A}$ºí $\dot{A}$ and

$\tilde{A} = \{\tilde{a}_1, \tilde{a}_2, \Lambda, \tilde{a}_m\}$ called the set of importance measure, applies to fuzzy operator $(\wedge,\vee)$ and $(\cdot,\vee)$; The values of the members of $\tilde{A}$ can be calculated by principle component analysis method of multi-dimensional statistics theory.

$\dot{A} = \{\dot{a}_1, \dot{a}_2, \Lambda, \dot{a}_m\}$ called the set of weight, applies to fuzzy operator $(\cdot,+)$ the value of the members of $\dot{A}$ can be calculated by hierarchy analysis process.

The determination of fuzzy vector

The members of fuzzy vector G denote weight of the fuzzy operator adopted. The value of each member of G is calculated by analytic hierarchy process, referring to precision of the result according to operation characteristic of each fuzzy operator.

Application example

In this section, fuzzy evaluating method is adopted to identify the Black Spots in 131 road sections and 46 intersections on the main and secondary arteries of Harbin city.

Through the investigation in Harbin, using fuzzy statistics and regression analysis method, the values of parameters of membership function u_j corresponding to index k_j of road sections and intersection are obtained (where $k_1 \sim k_4$ denote respectively the mortality rate of a hundred million vehicles per kilometer, the mortality rate of ten thousand vehicle, the equivalent accident rate of ten thousand vehicles, and the ponderance index of safety)(Shown in Table 1).

Table 1 parameter value of each membership function

u_j	a_j	b_j	c_j	R^2
u_1	0.145	1.423	29.35	0.995
u_2	0.264(0.345)	1.001(1.425)	0.008(0.002)	0.996(0.975)
u_3	0.018(0.112)	1.547(0.964)	0.10(0.028)	0.994(0.998)
u_4	0.324(0.227)	0.945(1.23)	0.21(0.19)	0.989(0.992)

Note: data matching intersections in ()

According to the data investigated from 1997 to 2000 in Harbin city, using principle component analysis method of statistics for functions of several variables and hierarchy analysis process respectively, the importance and weight of each evaluation index are obtained (shown in table 2).

Table 2 Importance and weight of each index

Importance	$\tilde{a}_1$	$\tilde{a}_2$	$\tilde{a}_3$	$\tilde{a}_4$
	0.448	0.496(0.628)	0.385(0.425)	0.396(0.548)
Weight	$\dot{\omega}_1$	$\dot{\omega}_2$	$\dot{\omega}_3$	$\dot{\omega}_4$
	0.321	0.215(0.346)	0.313(0.454)	0.151(0.200)

Note: data matching intersections in ()

According to operation characteristic of each fuzzy operator, referring to precision of the result, using hierarchy analysis, the weight of each fuzzy operator is calculated:

$$g_1 = 0.122 \quad g_2 = 0.230 \quad g_3 = 0.648$$

Using the fuzzy evaluation method proposed above, this paper evaluates road traffic safety of 131 road sections and 46 intersections of Harbin. The comprehensive evaluation values calculated are sorted respectively in Table 3 and Table 4 (Due to length limitation, the middle results, the name of the road sections, the beginning and terminus of the road sections, and the name of the intersections are not listed).

It can be seen from the table that, there are 23 road sections and 9 intersections in the 131 road sections and 46 intersections selected whose comprehensive evaluation values are less than 0.4, so, they can be considered as Black Spots and should be improved in accordance with the order in the table.

Table 3 Sorting of comprehensive evaluation value in part of road section in Harbin city

Number	Comprehensive evaluation value	Number	Comprehensive evaluation value	Number	Comprehensive evaluation value	Number	Comprehensive evaluation value	Number	Comprehensive evaluation value
130	0.122	53	0.417	94	0.711	117	0.842	118	0.903
1	0.143	62	0.420	68	0.717	122	0.843	105	0.911
27	0.154	54	0.427	42	0.717	116	0.846	58	0.920
129	0.171	128	0.427	22	0.721	20	0.848	50	0.921
2	0.203	83	0.428	21	0.726	78	0.853	63	0.922
86	0.216	33	0.438	41	0.726	49	0.865	59	0.924
90	0.235	34	0.444	25	0.729	114	0.865	109	0.924
47	0.257	16	0.445	23	0.731	77	0.873	108	0.926
110	0.264	95	0.446	45	0.732	111	0.875	92	0.932
131	0.269	37	0.468	24	0.738	18	0.876	103	0.936
3	0.288	56	0.494	44	0.745	52	0.876	104	0.938
120	0.297	35	0.500	26	0.746	57	0.876	101	0.941
87	0.314	4	0.502	46	0.748	72	0.876	102	0.941
66	0.335	100	0.504	28	0.757	73	0.878	85	0.942
112	0.342	67	0.511	39	0.765	80	0.878	119	0.942
6	0.364	7	0.511	19	0.769	113	0.880	97	0.943
30	0.375	127	0.512	40	0.778	70	0.884	98	0.943
10	0.376	88	0.568	48	0.779	69	0.886	124	0.945
91	0.387	36	0.571	13	0.804	76	0.888	99	0.954
12	0.387	31	0.573	11	0.806	82	0.889	93	0.956
38	0.394	19	0.584	17	0.818	81	0.890	96	0.963
61	0.398	89	0.589	29	0.826	115	0.892	106	0.971
51	0.399	64	0.600	79	0.826	60	0.896	107	0.982
55	0.404	75	0.601	14	0.827	125	0.897		
74	0.412	8	0.655	5	0.828	121	0.899		
123	0.412	65	0.665	15	0.830	71	0.902		
32	0.414	126	0.686	43	0.842	84	0.903		

Table 4 Sorting of comprehensive evaluation value in part of intersection in Harbin city

Number	Comprehensive evaluation value	Number	Comprehensive evaluation value	Number	Comprehensive evaluation value	Number	Comprehensive evaluation value	Number	Comprehensive evaluation value
41	0.245	10	0.409	29	0.481	16	0.626	5	0.812
39	0.289	28	0.424	19	0.495	42	0.648	30	0.812
7	0.314	2	0.436	27	0.495	18	0.648	12	0.878
13	0.316	37	0.436	35	0.512	26	0.674	20	0.941
25	0.334	46	0.449	24	0.545	11	0.696	21	0.941
4	0.356	3	0.452	44	0.567	15	0.696	45	0.941
14	0.362	38	0.452	40	0.567	31	0.696		
33	0.372	23	0.464	22	0.586	6	0.742		
9	0.396	32	0.464	34	0.598	43	0.779		
8	0.401	36	0.474	1	0.598	17	0.779		

Conclusion

This paper puts forward fuzzy evaluating method for identifying Black Spots. This method takes the mortality rate of a hundred million vehicles per kilometer, the mortality rate of ten thousand vehicles, the equivalent accident number of ten thousand vehicles, and the ponderance index of safety as indexes. Black Spots on part of the road sections and intersections in Harbin City are taken as examples.

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