Highway traffic safety evaluation based on evidence fusion and extension matter-element model

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Abstract
In order to reflect highway traffic safety level, on the basis of research on traffic safety assessment methods at home and abroad, we establish the highway traffic safety evaluation method based on extension matter-element model and evidential fusion. Firstly, we analyzed the affecting factors of traffic safety and establish the evaluation index system of highway traffic safety. Then the weight of each index is gained by using expert scoring method. Meanwhile, the article adopts evidence fusion to modify the index weight to avoid the influence of subjective factors. Finally set up the extension matter-element model of highway traffic safety, the degree of traffic safety condition belongs to one grade is quantitatively given, and the weight of evaluation index is more accurate by using extension set and dependent function. The example of application on the highway in Hebei Province has shown that the method can effectively evaluate the highway traffic safety level, and comprehensively reflect the traffic safety level of highway.
Key words: TRAFFIC SAFETY, EVIDENCE FUSION, EXTENSION MATTER-ELEMENT THEORY, INDEX WEIGHT, EVALUATION GRADE, EXTENSION INDEX

Introduction

The data compiled by the Word Health Organization shows that one million two hundred thousand people died in traffic accidents every year. The Guardian reported that there will be a traffic accident in average every half minute, and most of those deaths occur in the developing countries. According to the traffic administration bureau's latest statistics, one hundred thousand road traffic accidents occurred in the first half of this year in our country. These accidents lead to thirty thousand people died, one hundred and thirty thousand people injured and directly resulted in property loss up to 1.4 billion. The occurrence of traffic accidents has negative effect on the economic development and social stability. There are many causes for the traffic accident, they can be divided into four aspects: human, vehicle, road and traffic environment.

To understand the quantitative relationship between these factors and traffic accidents, and realize the evaluation of highway traffic safety, many scholars home and abroad have done a lot of research. For example, fuzzy comprehensive evaluation on expressway traffic safety was proposed by Li Guanfeng et al [1].Wu Yihu et al evaluate on highway traffic safety by using analytic hierarchy process (AHP) [2]. Chen Biwu et al proposed the establishment of highway traffic safety evaluation system using matter element model [3]. Chen Jun et al proposed highway traffic safety evaluation based on BP neural network [4, 5]. Peng Junlong [6] et al proposed road traffic safety evaluation based on a comprehensive method [7-9]. But these evaluation methods can not transform qualitative to quantitative problem. Partial evaluation method mainly depends on expert scoring, which have the strong subjective and can not be objective realization index quantification.

According to the expressway's own characteristics and previous experience, this paper established the evaluation index system of highway traffic safety and used AHP and expert scoring to determine the weight of each evaluation index. In order to eliminate the influence of subjective factor and the uncertainty, the method of evidence fusion was adopted [10, 11]. In this paper the method of extension was used and introducing the concept of matter element to set up the evaluation model of multi index parameters. There is a comprehensive evaluation on a Hebei highway traffic safety situation by using this model. The final evaluation of safety grade can be more precise through the calculation of extension index.

1 Establishment of highway traffic safety evaluation index system

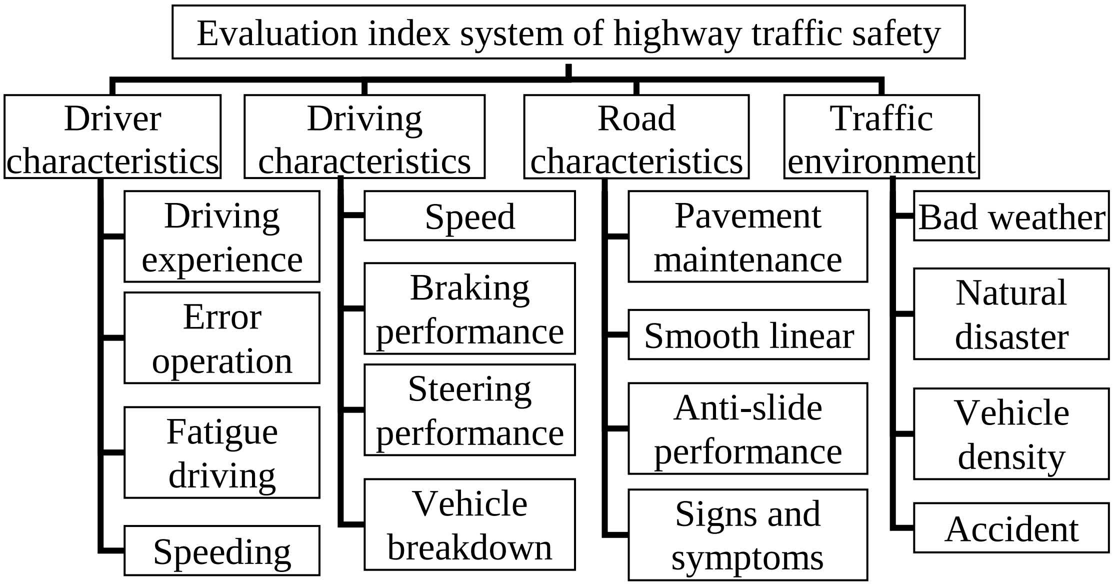

Figure 1. Evaluation index system of highway traffic safety

Considering the evaluation index system of the highway traffic safety is a complex system, the selection of the index requires to guarantee the accuracy of the model and do not repeat the evaluation factors. So according to the four aspects affecting the traffic safety, people, vehicles, road and traffic environment, appropriate index were chosen and three level of safety evaluation index system was set up [12-14] (Figure 1) .

2 D-S evidence fusion method

The method originated from the Harvard University mathematician Dempster to solve the probability method of limit mapping problem in 1960s. Then his student Shafer introduced the concept of belief functions on the basis of this approach, and formed a set of method based on the "evidence" and "fusion" to solve uncertainly problem, that is D-S evidence fusion. Many fusion methods are affected by the uncertain factors in the practical application, but the D-S can express and compose uncertain information. The advantage of D-S is that it can express "uncertain" and "not know" directly.

2.1 Basic principles

2.1.1 Frame of discernment

The set of all possible outcomes of the decision problem of composition named frame of discernment, represented with Θ.Each combination of all subsets of the power set in Θ denoted by 2^{Θ}.

2.1.2 Basic probability assignment function

The basic probability assignment function is an interval between 0 and 1. $m(A)$ represents a basic probability assignment function of A, on behalf of the exact confidence in A. For a frame of discernment, assuming a subset of A, B, C, which satisfied the formula, $m(A)+m(B)+m(C)<1$. It is shows that the evidence cannot be allocated to any other subset effectively. $m(\Theta)$ represented the uncertain of probability distribution, which satisfied the formula, $m(A)+m(B)+m(C)+m(\Theta)=1$.

2.1.3 Belief function

$Bel(A)$ is the sum of all the basic probability, eqn (1) and eqn (2):

$$Bel: 2^{\Theta} \to [0,1] \quad (1)$$

$$Bel(A)=\sum_{B \subseteq A} m(B), A \subseteq \Theta \quad (2)$$

Seen by the definition of belief function, $Bel(\phi)=0, Bel(\Theta)=1$。

2.1.4 Likelihood function

The likelihood function can be expressed as in eqn (3)and eqn (4).

$$pl: 2^{\Theta} \to [0,1] \quad (3)$$

$$pl(A)=1-Bel(\Theta-A), A \subseteq \Theta \quad (4)$$

The pl function is expressed as a no doubt on the extent of a thing. The relationship between belief function and likelihood function as follows in eqn (5).

$$pl(A) \geq Bel(A), A \subseteq \Theta \quad (5)$$

The minimum faith of A is $Bel(A)$, and the maximum faith is $pl(A)$.Uncertainty of A can be expressed as: $\mu(A)=pl(A)-Bel(A)$ $(Bel(A), pl(A))$ is called trust space.

2.2 Fusion rule

D-S evidence fusion uses orthogonal sum to get evidence. Let m_1 and m_2 are basic probability assignment functions in 2^{Θ}. Then get the orthogonal, $m=m_1+m_2$ is defined as in eqn(6) and eqn(7).

$$m(A)=c^{-1} \sum_{A_1 \cap A_2 = A} m_1(A_1) m_2(A_2), A \neq \Phi \quad (6)$$

$$m(\Phi)=0, A=\Phi \quad (7)$$

Where: $c=1-\sum_{A_1 \cap A_2 = \Phi} m_1(A_1) m_2(A_2)$ is called orthogonal constant, reflecting the same assumptions for the discrepancies between the evidence.

For several probability assignment functions, $m=m_1+m_2+\cdots+m_n$ is defined as in eqn(8) and eqn(9).

$$m(A)=c^{-1} \sum_{\cap A_i = A} \prod_{1 \leq i \leq n} m_i(A_i), A \neq \Phi \quad (8)$$

$$m(\Phi)=0, A=\Phi \quad (9)$$

Where: $c=1-\sum_{\cap A_i = \Phi} \prod_{1 \leq i \leq n} m_i(A_i)$

3 Establishment of extension matter element model

In 1983, extension theory was proposed by Cai Wen, a Chinese professor [15]. It was he who first used the method to solve the problem of incompatibility, and later the concept of matter-element was introduced [16]. The theory studies on the rules and methods to solve conflicts from qualitative to quantitative. The correlation function is used to describe the nature of things. It provides a quantitative of methods for the transforming of contradiction. At present, scholars at home and broad have used the extension matter-element theory in many aspects [17-19].

Matter-element theory is used to reflect the relationship between quality and quantity. Where N is the matter element, c is the characteristics, v is the value of the characteristics. The basic element is describe by an ordered three-dimensional (i.e., $R=(N \quad c \quad v)$) (matter-element for short); Object name, characteristics and values are called the three elements of matter-element. If there are several characteristics of a thing, it described by characteristic evaluation index ($c_1, c_2, \cdots, c_n$) and corresponding values ($v_1, v_2, \cdots, v_n$), then $R = (R_1 \quad R_2 \quad \cdots \quad R_n)$ is called n-dimensional matter-element. Extension element-model is as follows [20]:

3.1 Classical field and node field

3.1.1 Classical field

$$R_j = (N_j \quad c_i \quad v_{ji}) = \begin{bmatrix} N_j & c_1 & v_{j1} \\ & c_2 & v_{j2} \\ & \vdots & \vdots \\ & c_n & v_{jn} \end{bmatrix} = \begin{bmatrix} N_j & c_1 & (\mathrm{a}_{j1}, \mathrm{b}_{j1}) \\ & c_2 & (\mathrm{a}_{j2}, \mathrm{b}_{j2}) \\ & \vdots & \vdots \\ & c_n & (\mathrm{a}_{jn}, \mathrm{b}_{jn}) \end{bmatrix} \tag{10}$$

where, N_j is the grade in j class; subscript j represents the evaluation level; c_i as evaluation indexes of i; v_{ji} is the quantity value range about N_j with regard to c_i in the classical field, called the classical field.

3.1.2 Node field

$$R_p = (p \quad c_i \quad v_{pi}) = \begin{bmatrix} p & c_1 & v_{p1} \\ & c_2 & v_{p2} \\ & \vdots & \vdots \\ & c_n & v_{pn} \end{bmatrix} = \begin{bmatrix} p & c_1 & (\mathrm{a}_{p1}, \mathrm{b}_{p1}) \\ & c_2 & (\mathrm{a}_{p2}, \mathrm{b}_{p2}) \\ & \vdots & \vdots \\ & c_n & (\mathrm{a}_{pn}, \mathrm{b}_{pn}) \end{bmatrix} \tag{11}$$

Where p is the evaluation of all; v_{pi} is the quantity value range about p with regard to c_i, called node field.

3.2 Determine the matter-element

The data and analysis results that related to highway traffic safety evaluation index system can be defined as in eqn(12).

$$R_0 = \begin{bmatrix} p & c_1 & v_1 \\ & c_2 & v_2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix} \tag{12}$$

Where v_{i} is the quantity value range about p with regard to c_i, that is the data get from evaluating traffic safety index system.

3.3 Index weight

Delphi method, AHP and factor analysis method are all methods to determine the index weights. From the scientific and practical point of view, this paper uses analytic hierarchy process (AHP) and expert scoring to determine the index weight, and uses evidence fusion to correct the weight.

3.4 Relative degree calculation

After establishing the matter-element model, determine the relative function of the matter-element matrix to be evaluated and classical matter-element matrix based on characteristics of the evaluation index.

Relative degree is used to describe the degree j of each index on the attribution of specimens. The relative function is as follows in eqn(13), eqn(14) and eqn(15).

$$K_j(x_i) = \begin{cases} \dfrac{\rho(x_i, x_{ji})}{\rho(x_i, x_{pi}) - \rho(x_i, x_{ji})} & , x_i \notin x_{ji} \\ \dfrac{-\rho(x_i, x_{ji})}{|x_{ji}|} & , x_i \in x_{ji} \end{cases} \tag{13}$$

$$\rho(x_i, x_{ji}) = \left| x_i - \frac{1}{2}(\mathrm{a}_{ji} + \mathrm{b}_{ji}) \right| - \frac{1}{2}(\mathrm{b}_{ji} - \mathrm{a}_{ji}) \tag{14}$$

$$\rho(x_i, x_{pi}) = \left| x_i - \frac{1}{2}(\mathrm{a}_{pi} + \mathrm{b}_{pi}) \right| - \frac{1}{2}(\mathrm{b}_{pi} - \mathrm{a}_{pi}) \tag{15}$$

where $i = 1,2,...,n$; $\rho(x_i, x_{ji})$ is the distance between x_i and x_{ji}; $\rho(x_i, x_{pi})$ is the distance between x_i and x_{pi}

3.5 Grade determination

We obtain comprehensive relative degree $K_j(x)$ between the samples and multi indexes based on the relative degree $K_j(x_i)$ between the samples and each index, as in eqn(16).

$$K_j(x) = \sum_{i=1}^{n} \lambda_i K_j(x_i) \tag{16}$$

Where λ_i is weight coefficient.

When $K_m(x) = \max K_j(x), m \in \{1,2,..., j\}$, the sample belongs to grade N_{0m}. When $K_m(x) \leq 0$, it means that the sample do not belong to grade N_{0m}.

3.6 Calculation of extension index

Compared all levels of relative degree $K_j(x)$, the greater the numerical, the closer to the standard. The final evaluation index which is called extension index can be obtained by using method of grade determination [21].

The calculated weighted correlation levels $K_j(x)$ is compared with larger values closer representation of grade standards. The use of grading methods to calculate the level of the final evaluation of the measured indicators index, you can expand index, as in eqn(17) and eqn(18).

$$K_j(X)' = \frac{K_j(X) - \min K_j(X)}{\max K_j(X) - \min K_j(X)} \quad (17)$$

$$j^* = \frac{\sum_{j=1}^{5} j \times K_j(X)'}{\sum_{j=1}^{5} K_j(X)'} \quad (18)$$

Where j^* =extension index. It can help to determine the grade of traffic safety more accurately.

4 Example analysis

By using the highway traffic safety evaluation index system (in Figure 1), we can analysis the comprehensive application of matter-element model and evidence fusion, and evaluate traffic safety on a section of a Hebei highway.

4.1 Index weights determination

AHP is used to determine index weight. There are seven experts to score. The greater the weight, the bigger the effect on highway traffic safety. The reliability of expert information should be considered in calculation. The probabilities of 16 indexes given by 7 experts are as follows:

$$\mu_1 = (0.04,0.1,0.09,0.06,0.08,0.08,0.05,0.07,0.04,0.02,0.06,0.04,0.09,0.04,0.09,0.05)$$

$$\mu_2 = (0.05,0.12,0.08,0.07,0.08,0.09,0.04,0.08,0.03,0.01,0.05,0.04,0.1,0.04,0.08,0.04)$$

$$\mu_3 = (0.04,0.12,0.09,0.05,0.09,0.11,0.06,0.06,0.03,0.03,0.05,0.03,0.08,0.03,0.09,0.04)$$

$$\mu_4 = (0.06,0.11,0.07,0.08,0.07,0.11,0.05,0.08,0.04,0.01,0.07,0.05,0.09,0.02,0.07,0.02)$$

$$\mu_5 = (0.07,0.09,0.08,0.07,0.09,0.1,0.05,0.09,0.02,0.04,0.06,0.02,0.11,0.02,0.06,0.03)$$

$$\mu_6 = (0.04,0.1,0.09,0.07,0.07,0.09,0.06,0.09,0.05,0.01,0.05,0.03,0.1,0.03,0.08,0.04)$$

$$\mu_7 = (0.03,0.12,0.1,0.05,0.05,0.08,0.05,0.08,0.04,0.01,0.06,0.04,0.12,0.05,0.07,0.05)$$

The reliabilities of seven experts are respectively 0.96, 0.9, 0.85, 0.8, 0.8 and 0.75.

Therefore, we can get the basic probability assignment function:

$$m_1 = (0.038,0.095,0.0855,0.057,0.08,0.076,0.0475,0.0665,$$
$$0.038,0.019,0.057,0.038,0.0855,0.038,0.0855,0.0475,0.05)$$

$$m_2 = (0.045,0.108,0.072,0.063,0.07,0.081,0.036,0.072,$$
$$0.027,0.009,0.045,0.036,0.09,0.036,0.072,0.036,0.1)$$

$$m_3 = (0.034,0.102,0.0765,0.0425,0.08,0.0935,0.051,0.051,$$
$$0.0255,0.0255,0.0425,0.0255,0.068,0.0255,0.0765,0.034,0.15)$$

$$m_4 = (0.048,0.088,0.056,0.064,0.06,0.088,0.04,0.064,$$
$$0.032,0.008,0.056,0.04,0.072,0.016,0.056,0.016,0.2)$$

$$m_5 = (0.056,0.072,0.064,0.056,0.07,0.08,0.04,0.072,$$
$$0.016,0.032,0.048,0.016,0.088,0.016,0.048,0.024,0.2)$$

$$m_6 = (0.03,0.075,0.0675,0.0525,0.05,0.0675,0.045,0.0675,$$
$$0.0375,0.0075,0.0375,0.0225,0.075,0.0225,0.06,0.03,0.25)$$

$$m_7 = (0.021,0.084,0.07,0.035,0.04,0.056,0.035,0.056,$$
$$0.028,0.007,0.042,0.028,0.084,0.035,0.049,0.035,0.3)$$

The fusion results are shown in Table 1.

Table 1. Index weight fusion

	$m(A_1)$	$m(A_2)$	$m(A_3)$	$m(A_4)$	$m(A_5)$	$m(A_6)$	$m(A_7)$	$m(A_8)$	$m(A_9)$
m_{I}	0.0375	0.1216	0.0885	0.0601	0.0806	0.0861	0.0399	0.0727	0.0299
m_{II}	0.0331	0.1419	0.0938	0.0540	0.0861	0.0995	0.0397	0.0679	0.0251
m_{III}	0.0328	0.1548	0.0912	0.0559	0.0840	0.1100	0.0372	0.0693	0.0232
m_{IV}	0.0334	0.1587	0.0917	0.0553	0.0875	0.1173	0.0347	0.0728	0.0192
m_{V}	0.0305	0.1657	0.0942	0.0545	0.0854	0.1200	0.0337	0.0751	0.0185
m_{VI}	0.0275	0.1776	0.0977	0.0511	0.0798	0.1192	0.0318	0.0750	0.0173
	$m(A_{10})$	$m(A_{11})$	$m(A_{12})$	$m(A_{13})$	$m(A_{14})$	$m(A_{15})$	$m(A_{16})$	$m(\Theta)$	
m_{I}	0.0122	0.0508	0.0337	0.1003	0.0337	0.0885	0.0399	0.0242	
m_{II}	0.0118	0.0463	0.0280	0.1007	0.0280	0.0938	0.0350	0.0155	
m_{III}	0.0095	0.0466	0.0269	0.1045	0.0231	0.0912	0.0286	0.0114	
m_{IV}	0.0095	0.0448	0.0221	0.1150	0.0191	0.0857	0.0247	0.0084	
m_{V}	0.0079	0.0419	0.0197	0.1206	0.0171	0.0859	0.0228	0.0067	
m_{VI}	0.0069	0.0404	0.0184	0.1297	0.0165	0.0838	0.0217	0.0055	

After sixth fusion, uncertainty of weight decreased to 0.0055, and can be ignored.

4.2 Classical field and node field

The highway traffic safety evaluation system is divided into safe enough, relatively safe, critical safe, less safe and unsafe. Considering actual situation, each index was given a value. These values and grading standards are shown in Table 2.

Table2. Value and grading standard of index

Evaluation index	Index value	weight	Unit	Index classification standard				
				Safe enough	Relatively safe	Critical safe	Less safe	Unsafe
Driving experience	8	0.0275	Year	(10,30)	(5,10)	(3,5)	(1,3)	(0,1)
Error operation	0.8	0.1776	‰	(0,1)	(1,3)	(3,5)	(5,7)	(7,10)
Fatigue driving	1.2	0.0977	‰	(0,1)	(1,3)	(3,5)	(5,7)	(7,10)
Speeding	1.4	0.0511	‰	(0,2)	(2,4)	(4,6)	(6,8)	(8,10)
Speed	95	0.0798	Km/h	(60,80)	(80,90)	(90,110)	(110,120)	(120,140)
Braking performance	90	0.1192	No	(80,100)	(60,80)	(40,60)	(20,40)	(0,20)
Steering performance	95	0.0318	No	(80,100)	(60,80)	(40,60)	(20,40)	(0,20)
Vehicle breakdown	1.4	0.0750	‰	(0,1)	(1,2)	(2,3)	(3,5)	(5,10)
Pavement maintenance	96	0.0173	No	(80,100)	(60,80)	(40,60)	(20,40)	(0,20)

Smooth linear	90	0.0069	No	(80,100)	(60,80)	(40,60)	(20,40)	(0,20)
Anti-slide performance	85	0.0404	No	(80,100)	(60,80)	(40,60)	(20,40)	(0,20)
Signs and symptoms	99	0.0184	%	(98,100)	(96,98)	(94,96)	(92,94)	(90,92)
Bad weather	82	0.1297	No	(80,100)	(60,80)	(40,60)	(20,40)	(0,20)
Natural disaster	96	0.0165	No	(80,100)	(60,80)	(40,60)	(20,40)	(0,20)
Vehicle density	6	0.0838	Vehicles / km.	(0,5)	(5,10)	(10,20)	(20,30)	(30,40)
Accident	3	0.0217	Times / million vehicle kilometers	(0,2)	(2,4)	(4,6)	(6,8)	(8,10)

4.3 Results of comprehensive evaluation

The relative degree of each index and the comprehensive relative degree are shown in Table 3.

Table 3. Evaluation result

Evaluation index	Correlation Degree				
	Safe enough	Relatively safe	Critical safe	Less safe	Unsafe
Driving experience	-0.0055	0.0110	-0.0075	-0.0106	-0.0128
Error operation	0.0355	-0.0355	-0.1302	-0.1492	-0.1573
Fatigue driving	-0.0140	0.0098	-0.0586	-0.0743	-0.0810
Speeding	0.0153	-0.0153	-0.0332	-0.0392	-0.0422
Speed	-0.0239	-0.0100	0.0200	-0.0239	-0.0333
Braking performance	0.0596	-0.0596	-0.0894	-0.0993	-0.1043
Steering performance	0.0080	-0.0239	-0.0278	-0.0292	-0.0298
Vehicle breakdown	-0.0167	0.0300	-0.0225	-0.0400	-0.0540
Pavement maintenance	0.0035	-0.0138	-0.0156	-0.0161	-0.0164
Smooth linear	0.0035	-0.0035	-0.0052	-0.0058	-0.0060
Anti-slide performance	0.0101	-0.0101	-0.0253	-0.0303	-0.0328
Signs and symptoms	0.0092	-0.0092	-0.0138	-0.0153	-0.0161
Bad weather	0.0130	-0.0130	-0.0713	-0.0908	-0.1005
Natural disaster	0.0033	-0.0132	-0.0149	-0.0154	-0.0157
Vehicle density	-0.0120	0.0168	-0.0335	-0.0587	-0.0670
Accident	-0.0054	0.0109	-0.0054	-0.0109	-0.0136
Comprehensive Evaluation	0.0834	-0.1287	-0.5343	-0.7088	-0.7828

According to the evaluation standard of extension matter-element model, the grade of this highway is safe enough. The extension index is 1.74 by calculating. It shows that the grade of this highway belongs to the first security, but close to the second security.

Conclusions

(1)Method in this paper fuse, the weights of experts with using evidence fusion method. This method reduces uncertainty of the index weight, and improves the accuracy of evaluation.

(2)According to the factors affecting highway traffic safety, the extension matter-element model was established. We can get the safety grade by calculating the relative degree of each index and comprehensive relative degree.

(3)It reflects the degree of the evaluation results to a level of results and determines the traffic safety grade more precisely by calculating the extension index.

(4)Software can be used in the calculations, which could simplify the calculation greatly.

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