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Research Article

Traffic Safety Evaluation Model for Highway in Cold Region Based on Fuzzy Theory

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Abstract: Aiming at the problem of highway traffic safety in cold region, traffic safety evaluation model is established by applying the fuzzy comprehensive evaluation theory and the highway safety level is judged. On the basis of the comprehensive analysis of the factors affecting highway traffic safety, the index system for highway traffic safety evaluation is established combining with expert evaluation method, the weight value of influence factors in the traffic incident are confirmed. The comprehensive evaluating result is obtained. The value is 1.8858 in range from 1 to 2. The result shows that the highway safety level in the certain cold region is good. The assessment model can offer the theoretical foundation for highway safety evaluation in other cold region.

Keywords: Cold Region, fuzzy theory, evaluation model, traffic safety

INTRODUCTION

With the development of economy, Highway construction has come into fast development stage. At the same time, the high-speed flow and gather of people and the rapid growth amount of vehicle make the traffic demand increasingly strong, the transportation security problems become the inevitable result of social economic development (Ma, 2012). In recent years, the highway traffic accident rate remains high and the highway traffic accidents are particularly serious in the cold region. Scholars at home and abroad have devoted to the researches of highway traffic safety evaluation and have achieved significant results. Foreign scholars propose to use Poisson regression model (Miaou and Lum, 1993), negative binomial regression model (Hinde and Demetrio, 1998), zero-inflated probability model (Lord *et al*., 2005), to analyze the relationship between traffic accidents and the influence factors. Zhao *et al*. (2012) from Chongqing Jiaotong University establish a total vehicle travel safety rating model by using the Analytic Hierarchy Process to calculate the parameters weight. Yao *et al*. (2010) establish safety rating evaluation system based on the three aspects of road alignment, vehicle design parameters and road-vehicle correlation parameters and build the mountain road safety rating model combining the fuzzy mathematics method. As it is difficulty to establish the scientific comprehensive model accords with current situation, Wang and Nan (2008) propose macroscopic evaluation model based on fuzzy logic. Due to the special geography, climatic conditions and the complex road environment, road traffic accidents in cold region have distinguishing features different from other parts. Traffic accident statistics analysis showed that the accidents happened in cold region had seasonal variations. In winter, traffic accident rate was obviously improved. The highway traffic safety fuzzy evaluation model established in this study is significance for reducing the traffic accident rate, which can judge the highway safety level through finding out and analyzing highway traffic safety factors in cold region.

THE FUZZY COMPREHENSIVE EVALUATION THEORY

Applying the fuzzy comprehensive evaluation theory will arrive at a scientific evaluation conclusion through selecting the neighborhood of each factor in a system reasonably and evaluating the factors. Its fundamental theory is:

$$F = B \times S^T \tag{1}$$

where,
F = The total score of the system
B = The evaluation matrix of the system
S^T = Factor fraction:

$$B = A \cdot R \tag{2}$$

where,
B = The evaluation matrix of the system
A = The weight distribution set of each factor
R = Evaluation matrix:

$$B_i = A_i \cdot R_i \tag{3}$$

where,
B_i = Sub-factors of evaluation matrix in the system

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Table 1: Gradation index system

A gradation	*B* gradation	*C* gradation
The highway safety level evaluation index system in cold region *A*	Dimly-lit in morning and evening in winter b_1	-
	Environmental factor in winter b_2	Dazzle C_{21}
		Snow C_{22}
		Hail C_{23}
		Frost fog C_{24}
	Influence of low temperature on performance of automobile b_3	Inferior braking C_{31}
		Steering inoperative C_{32}
		Lighting inoperative C_{33}
	Low attachment coefficient on snowy road b_4	-
	Driver personal factors b_5	Driving skill C_{51}
		Driving habits C_{52}
		Self-diathesis C_{53}
		Adaptability to the road in the cold region C_{54}

A_i = The weight distribution set of sub-factors
R_i = Evaluation matrix of sub-factors

Single ranking weight vector:

$$W = \left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}} \Bigg/ \sum_{k=1}^{n}\left(\prod_{j=1}^{n} a_{kj}\right)^{\frac{1}{n}} \tag{4}$$

Maximum characteristic root of matrix:

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \tag{5}$$

Consistency index of matrix:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{6}$$

Mean random Consistency index:

$$RI = -0.514+2.1784\lg n \ (n>3) \tag{7}$$

The steps of applying the fuzzy comprehensive evaluation are as followed. Firstly, determine quantitative criteria. Secondly, determine judgment matrix. Thirdly, Single-level sequencing and consistency check, calculate maximum characteristic root $\lambda_{\max}$ of the judgment matrix A and its corresponding single ranking weight vector W and then calculate the random consistency ratio CR, carry on the consistency check:

$$CR = \frac{CI}{RI}\begin{cases} = 0 & A \ completely consistency \\ < 0.1 & A \ satisfying consistency \\ \geq 0.1 & A \ nonsatisfying consistency \end{cases} \tag{8}$$

Then establish evaluation set U = $\{U_1, U_2, U_3, U_4$ and $U_5\}$, determine the safety level of highway in cold region, the evaluation set is U = {excellent, good, medium, low-risk, high risk}, which correspond grade are 1, 2, 3, 4 and 5 respectively.

HIGHWAY SAFETY EVALUATION SYSTEM IN COLD REGION

Applying the multi-level comprehensive evaluation method to evaluate highway safety level in cold region based on many influence factors, the safety comprehensive evaluation index system for highway in the typical cold region Heilongjiang province is established. The highway safety comprehensive evaluation index system in cold region is shown in Table 1.

HIGHWAY SAFETY COMPREHENSIVE EVALUATION IN COLD REGION

- **Evaluation factors sets:** The factors related to highway safety level comprehensive evaluation in cold region have been divided into 5 subsets, which are $v = \{v_1,v_2,v_3,v_4,v_5\}$ corresponding to {dimly-lit in morning and evening in winter, environmental factor in winter, influence of low temperature on performance of automobile, low attachment coefficient on snowy road, driver personal factors}.
- **Sub-factors set of evaluation factors sets:** Sub-factors sets of judgment factors sets are $v_1 = \{v_{11}\}$ = {dimly-lit in morning and evening in winter}; $v_2 = \{v_{21},v_{22},v_{23},v_{24}\}$ = {dazzle, hail, snow, frost fog};$v_3 = \{v_{31},v_{32},v_{33}\}$ = {inferior braking, steering inoperative, lighting inoperative};$v_4 = \{v_{41}\}$ = {low attachment coefficient on snowy road}; $v_5 = \{v_{51},v_{52},v_{53},v_{54}\}$ = {driving skill, driving habits, self-diathesis, adaptability to the road in the cold region}.
- Determine the quantitative standard by using of ratio scale put forward by A. L. Sarry single ranking calculations of evaluation matrices, *A-B* level, B_2-C_2 level, B_3-C_3 level, B_5-C_5 level and consistency check are shown in Table 2, 3, 4 and 5.
- General sequence and consistency check: Based on single sequence results and general sequence weight of evaluation factors, generals equence weight.

Table 2: Judgment matrix of *A-B*

A factor	B_1 dimly-lit in morning and evening in winter	B_2 environmental factor in winter	B_3 influence of low temperature on performance of automobile	B_4 low attachment coefficient on snowy road	B_5 driver personal factors	Single-level sequencing weight W_i
B_1	1	1/2	1/2	2/5	1/2	0.1582
B_2	2	1	1	4/5	1/2	0.2143
B_3	2	1	1	4/5	1	0.1887
B_4	5/2	5/4	5/4	1	5/4	0.2347
B_5	1	2	2	4/5	1	0.2041

λ_{max}, *CI*, *RI*, *CR* can be obtained based on formulas (4), (5), (6), (7), (8) that is $\lambda_{max} = 5.0603$; $CI = 0.01508$; $RI = 1.01$; $CR = 0.015<0.10$

Table 3: Judgment matrix of B_2-C_2

B_2 factor	C_{21} dazzle	C_{22} snow	C_{23} hail	C_{24} frost fog	Single-level sequencing weight W_i
C_{21}	1	4	4/5	4	0.2500
C_{22}	1/4	1	1/5	1	0.1938
C_{23}	5/4	5	1	5	0.3000
C_{24}	1/4	1	1/5	1	0.2562

λ_{max}, *CI*, *RI*, *CR* can be obtained based on formulas (4), (5), (6), (7), (8) that is $\lambda_{max} = 4.1065$; $CI = 0.0355$; $RI = 0.80$; $CR = 0.044<0.10$

Table 4: Judgment matrix of B_3-C_3

B_3 factor	C_{31} inferior braking	C_{32} steering inoperative	C_{33} lighting inoperative	Single-level sequencing weight W_i
C_{31}	1	5/4	5	0.3967
C_{32}	4/5	1	4	0.3471
C_{33}	1/5	1/4	1	0.2562

λ_{max}, *CI*, *RI*, *CR* can be obtained based on formulas (4), (5), (6), (7), (8) that is $\lambda_{max} = 3.00068$; $CI = 0.00034$; $RI = 0.52$; $CR = 0.0006538<0.10$

Table 5: Judgement matrix of B_5-C_5

B_5 factor	C_{51} driving skill	C_{52} driving habits	C_{53} self-diathesis	C_{54} adaptability to the road in the cold region	Single-level sequencing weight W_i
C_{51}	1	1	1	4/5	0.2544
C_{52}	1	1	1	4/5	0.2426
C_{53}	1	1	1	4/5	0.2485
C_{54}	5/4	5/4	5/4	1	0.2545

λ_{max}, *CI*, *RI*, *CR* can be obtained based on formulas (4), (5), (6), (7), (8) that is $\lambda_{max} = 4.0036$; $CI = 0.0012$; $RI = 0.80$; $CR = 0.0015<0.10$

Table 6: Weight and rank of factors

The highway safety level evaluation index system in cold region	Factor	Weight	Factor	Weight	Factor	*C* level general sequence weight ranking weight
	Dimly-lit in morning and evening in winter	0.1582				
	Environmental factor in winter	0.2143	Dazzle	0.2500	C_{21}	0.0536
			Snow	0.1938	C_{22}	0.0415
			Hail	0.3000	C_{23}	0.0643
			Frost fog	0.2562	C_{24}	0.0549
	Influence of low temperature on performance of automobile	0.1887	Inferior braking	0.3967	C_{25}	0.0749
			Steering inoperative	0.3471	C_{32}	0.0655
			Lighting inoperative	0.2562	C_{33}	0.0483
	Low attachment coefficient on snowy road	0.2347				
	Driver personal factors	0.2041	Driving skill	0.2544	C_{51}	0.0519
			Driving habits	0.2426	C_{52}	0.0495
			Self-diathesis	0.2485	C_{53}	0.0507
			Adaptability to the road in the cold region	0.2545	C_{54}	0.0519

of each evaluation factor in *B* level and *C* level can be obtained. General sequence weight P_{ij} can be calculated by $P_{ij} = W_i \times B_{ij}$ ($I = 1, 2, 3$ and 4; $j = 1, 2, 3, 4$ and 5).

- **Scheme evaluation of highway safety level:**
- **Establish the evaluation matrix:** Scheme evaluation result is shown in Table 7 through marking and accessing the factors related to highway safety in cold region by experts.

Each judgment matrix of environmental factor in winter, influence of low temperature on performance of

Table 7: Assessment grade of influencing factors of highway traffic safety in cold region

	Grade				
Factor	Excellent	Good	Medium	Low-risk	High risk
v_{11}	1	3	2	2	2
v_{21}	0	0	3	4	3
v_{22}	2	2	1	3	2
v_{23}	0	0	0	2	8
v_{24}	1	0	1	3	5
v_{31}	0	0	0	1	9
v_{32}	1	1	0	3	5
v_{33}	2	2	1	4	1
v_{41}	0	0	1	2	7
v_{51}	0	0	2	3	5
v_{52}	0	0	0	9	1
v_{53}	0	0	1	6	3
v_{54}	0	0	1	5	4

automobile, driver personal factors is shown as follows according to Table7:

$$D_2 = \begin{bmatrix} 0/10 & 0/10 & 3/10 & 4/10 & 3/10 \\ 2/10 & 2/10 & 1/10 & 3/10 & 2/10 \\ 0/10 & 0/10 & 0/10 & 2/10 & 8/10 \\ 1/10 & 0/10 & 1/10 & 3/10 & 5/10 \end{bmatrix}; \quad D_3 = \begin{bmatrix} 0/10 & 0/10 & 0/10 & 1/10 & 9/10 \\ 1/10 & 1/10 & 0/10 & 3/10 & 5/10 \\ 2/10 & 2/10 & 1/10 & 4/10 & 1/10 \end{bmatrix};$$

$$D_5 = \begin{bmatrix} 0/10 & 0/10 & 2/10 & 3/10 & 5/10 \\ 0/10 & 0/10 & 0/10 & 9/10 & 1/10 \\ 0/10 & 0/10 & 1/10 & 6/10 & 3/10 \\ 0/10 & 0/10 & 1/10 & 5/10 & 4/10 \end{bmatrix}$$

- **Confirm fuzzy relation matrix:** Conduct One-level fuzzy comprehensive assessment is conducted and the fuzzy relation matrix $R = (R_2, R_3 \text{ and } R_5)^{\mathrm{T}}$ is confirmed:

$$R_2 = W_2^{\mathrm{T}} \cdot D_2 = (w_{21}, w_{22}, w_{23}, w_{24}, w_{25}) \cdot D_2$$
$$= (0.2500,\ 0.1938,\ 0.3000,\ 0.2562) \cdot \begin{bmatrix} 0/10 & 0/10 & 3/10 & 4/10 & 3/10 \\ 2/10 & 2/10 & 1/10 & 3/10 & 2/10 \\ 0/10 & 0/10 & 0/10 & 2/10 & 8/10 \\ 1/10 & 0/10 & 1/10 & 3/10 & 5/10 \end{bmatrix}$$
$$= (0.0644,\ 0.0388,\ 0.1200,\ 0.2950,\ 0.4819)$$

$$R_3 = W_3^{\mathrm{T}} \cdot D_3$$
$$= (0.3967,\ 0.3471,\ 0.2562) \cdot \begin{bmatrix} 0/10 & 0/10 & 0/10 & 1/10 & 9/10 \\ 1/10 & 1/10 & 0/10 & 3/10 & 5/10 \\ 2/10 & 2/10 & 1/10 & 4/10 & 1/10 \end{bmatrix}$$
$$= (0.0163,\ 0.0163,\ 0.0049,\ 0.0467,\ 0.1050)$$

$$R_5 = (0.2544,\ 0.2426,\ 0.2485,\ 0.2545) \cdot \begin{bmatrix} 0/10 & 0/10 & 2/10 & 3/10 & 5/10 \\ 0/10 & 0/10 & 0/10 & 9/10 & 1/10 \\ 0/10 & 0/10 & 1/10 & 6/10 & 3/10 \\ 0/10 & 0/10 & 1/10 & 5/10 & 4/10 \end{bmatrix}$$
$$= (0,\ 0,\ 0.1012,\ 0.5710,\ 0.3278)$$

So the fuzzy relation matrix R can be obtained.

$$R = (R_2\ \ R_3\ \ R_5)^{\mathrm{T}}$$

- **Confirm evaluation vector:** One-level fuzzy comprehensive assessment is conducted and the evaluation vector of the evaluated object is confirmed.

$$E = W^{\mathrm{T}} \cdot R = (0.1582,\ 0.2143,\ 0.1887,\ 0.2347,\ 0.2041) \cdot \begin{bmatrix} 0.0644 & 0.0388 & 0.1200 & 0.2950 & 0.4819 \\ 0.0163 & 0.0163 & 0.0049 & 0.0467 & 0.1050 \\ 0 & 0 & 0.1012 & 0.5710 & 0.3278 \end{bmatrix}$$
$$= (0.0169,\ 0.0114,\ 0.0473,\ 0.1886\ \ 0.1900)$$

- Determine comprehensive evaluation value of Scheme evaluation based on evaluation weight coefficient matrix.

$$P_1 = E \cdot Q = (0.0169, 0.0114, 0.0473, 0.1887, 0.1900) \cdot \{1,2,3,4,5\}^T$$
$$= 1.8858$$

$1 < P_1 = 1.8858 < 2$, so the highway traffic safety level in a region of Heilongjiang Province in winter is good.

CONCLUSION

This study comprehensively analyzes the factors influencing the highway traffic safety in typical cold region of Heilongjiang Province in winter for studying the problems of highway traffic safety in cold region, selects evaluation index and establishes highway traffic safety evaluation system in cold region. Highway traffic safety fuzzy comprehensive evaluation model in cold region can be established through conducting quantitative evaluation on highway traffic safety in cold region combining with the fuzzy theory , transforming the multi-objective evaluation problems of the highway traffic safety into single objective evaluation, determining the weight value of influence factors in the traffic incident. The highway traffic safety level in the region in winter is good for the comprehensive evaluation value of scheme evaluation $1 < P_1 = 1.8858 < 2$. The highway safety level evaluation index system in cold region built in this study can more accurately reflect the traffic safety condition in a region and offer theoretical foundation for highway safety evaluation in other cold region.

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