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:

\[ F = B \times S^T \]  

where,

- \( F \) = The total score of the system
- \( B \) = The evaluation matrix of the system
- \( S^T \) = Factor fraction:

\[ B = A \cdot R \]  

where,

- \( B \) = The evaluation matrix of the system
- \( A \) = The weight distribution set of each factor
- \( R \) = Evaluation matrix:

\[ B_i = A_i \cdot R_i \]  

where,

- \( B_i \) = Sub-factors of evaluation matrix in the system

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The highway safety level evaluation index system in cold region \( A \)

<table>
<thead>
<tr>
<th>( A ) gradation</th>
<th>( B ) gradation</th>
<th>( C ) gradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimly-lit in morning and evening in winter ( b_1 )</td>
<td>-</td>
<td>Dazzle ( C_{21} )</td>
</tr>
<tr>
<td>Environmental factor in winter ( b_2 )</td>
<td>Snow ( C_{32} )</td>
<td></td>
</tr>
<tr>
<td>Influence of low temperature on performance of automobile ( b_3 )</td>
<td>Hail ( C_{33} )</td>
<td></td>
</tr>
<tr>
<td>Low attachment coefficient on snowy road ( b_4 )</td>
<td>Frost fog ( C_{34} )</td>
<td></td>
</tr>
<tr>
<td>Driver personal factors ( b_5 )</td>
<td>(-)</td>
<td>Driving skill ( C_{31} )</td>
</tr>
<tr>
<td>Adaptability to the road in the cold region ( C_{54} )</td>
<td>Driving habits ( C_{32} )</td>
<td></td>
</tr>
<tr>
<td>Self-diathesis ( C_{35} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( A_i = \) The weight distribution set of sub-factors

\( R_i = \) Evaluation matrix of sub-factors

Single ranking weight vector:

\[
W = \left( \prod_{j=1}^{n} a_{ij} \right)^{1/n} / \sum_{i=1}^{n} \left( \prod_{j=1}^{n} a_{ij} \right)^{1/n}
\]  

Maximum characteristic root of matrix:

\[
\lambda_{\text{max}} = 1 \sum_{i=1}^{n} \left( AW \right)_{i} / W_i
\]  

Consistency index of matrix:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]  

Mean random Consistency index:

\[
RI = -0.514+2.1784\text{lg}n \quad (n>3)
\]  

The steps of applying the fuzzy comprehensive evaluation method are as followed. Firstly, determine quantitative criteria. Secondly, determine judgment matrix. Thirdly, Single-level sequencing and consistency check, calculate maximum characteristic root \( \lambda_{\text{max}} \) 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:

\[
CR = \frac{CI}{RI}
\]

- \( A \) completely consistency: \( CR = 0 \)
- \( A \) satisfying consistency: \( 0 < CR < 0.1 \)
- \( A \) nonsatisfying consistency: \( CR \geq 0.1 \)

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

HIGHPWAY 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.

HIGHPWAY 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, \( B_2-C_3 \) 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 sequence weight.
Table 2: Judgment matrix of \( A-B \)

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

\( \lambda_{max}, CI, RI, CR \) 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 \( B_2-C_2 \)

<table>
<thead>
<tr>
<th>( B_2 ) factor</th>
<th>( C_{21} ), dazzle</th>
<th>( C_{22} ), snow</th>
<th>( C_{23} ), hail</th>
<th>( C_{24} ), frost fog</th>
<th>Single-level sequencing weight ( W_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{21} )</td>
<td>1</td>
<td>4</td>
<td>5/4</td>
<td>4</td>
<td>0.2500</td>
</tr>
<tr>
<td>( C_{22} )</td>
<td>1/4</td>
<td>1</td>
<td>1/5</td>
<td>1</td>
<td>0.1938</td>
</tr>
<tr>
<td>( C_{23} )</td>
<td>5/4</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>0.3000</td>
</tr>
<tr>
<td>( C_{24} )</td>
<td>1/4</td>
<td>1</td>
<td>1/5</td>
<td>1</td>
<td>0.2562</td>
</tr>
</tbody>
</table>

\( \lambda_{max}, CI, RI, CR \) can be obtained based on formulas (4), (5), (6), (7), (8) that is \( \lambda_{max} = 4.1065; CI = 0.05355; RI = 0.80; CR = 0.044<0.10 \)

Table 4: Judgment matrix of \( B_3-C_3 \)

<table>
<thead>
<tr>
<th>( B_3 ) factor</th>
<th>( C_{31} ), inferior braking</th>
<th>( C_{32} ), steering inoperative</th>
<th>( C_{33} ), lighting inoperative</th>
<th>Single-level sequencing weight ( W_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{31} )</td>
<td>1</td>
<td>5/4</td>
<td>5</td>
<td>0.3967</td>
</tr>
<tr>
<td>( C_{32} )</td>
<td>4/5</td>
<td>1</td>
<td>4</td>
<td>0.3471</td>
</tr>
<tr>
<td>( C_{33} )</td>
<td>1/4</td>
<td>1</td>
<td>1</td>
<td>0.2562</td>
</tr>
</tbody>
</table>

\( \lambda_{max}, CI, RI, CR \) 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: Judgment matrix of \( B_4-C_4 \)

<table>
<thead>
<tr>
<th>( B_4 ) factor</th>
<th>( C_{41} ), driving skill</th>
<th>( C_{42} ), driving habits</th>
<th>( C_{43} ), self-diathesis</th>
<th>( C_{44} ), adaptability to the road in the cold region</th>
<th>Single-level sequencing weight ( W_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{41} )</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4/5</td>
<td>0.2544</td>
</tr>
<tr>
<td>( C_{42} )</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4/5</td>
<td>0.2426</td>
</tr>
<tr>
<td>( C_{43} )</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4/5</td>
<td>0.2485</td>
</tr>
<tr>
<td>( C_{44} )</td>
<td>5/4</td>
<td>5/4</td>
<td>5/4</td>
<td>1</td>
<td>0.2545</td>
</tr>
</tbody>
</table>

\( \lambda_{max}, CI, RI, CR \) 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

<table>
<thead>
<tr>
<th>Factor</th>
<th>Weight</th>
<th>Factor</th>
<th>Weight</th>
<th>Factor</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimly-lit in morning and evening in winter</td>
<td>0.1582</td>
<td>Dazzle</td>
<td>0.2500</td>
<td>C_{31}</td>
<td>0.0536</td>
</tr>
<tr>
<td>Environmental factor in winter</td>
<td>0.2143</td>
<td>Snow</td>
<td>0.1938</td>
<td>C_{22}</td>
<td>0.0415</td>
</tr>
<tr>
<td>Influence of low temperature on performance of automobile</td>
<td>0.1887</td>
<td>Hail</td>
<td>0.3000</td>
<td>C_{23}</td>
<td>0.0643</td>
</tr>
<tr>
<td>Low attachment coefficient on snowy road</td>
<td></td>
<td>Frost fog</td>
<td>0.2562</td>
<td>C_{34}</td>
<td>0.0549</td>
</tr>
<tr>
<td>Driver personal factors</td>
<td>0.2041</td>
<td>Inferior braking</td>
<td>0.3967</td>
<td>C_{24}</td>
<td>0.0749</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Steering inoperative</td>
<td>0.3471</td>
<td>C_{35}</td>
<td>0.0655</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lighting inoperative</td>
<td>0.2562</td>
<td>C_{36}</td>
<td>0.0483</td>
</tr>
</tbody>
</table>

The highway safety level evaluation index system in cold region

| Calculation of each evaluation factor in B level and C level can be obtained. General sequence weight \( P_j \) can be calculated by \( P_j = W_i \times B_j (I = 1, 2, 3 and 4; j = 1, 2, 3, 4 and 5) \). |

- **Scheme evaluation of highway safety level:** 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

<table>
<thead>
<tr>
<th>Factor</th>
<th>Excellent</th>
<th>Good</th>
<th>Medium</th>
<th>Low-risk</th>
<th>High risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>v₁₁</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>v₂₁</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>v₂₂</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>v₂₃</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>v₂₄</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>v₃₁</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>v₃₂</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>v₃₃</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>v₃₄</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>v₄₁</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>v₄₂</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>v₄₃</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>v₄₄</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

automobile, driver personal factors is shown as follows according to Table 7:

\[
D_2 = \begin{bmatrix}
0/10 & 0/10 & 3/10 & 4/10 & 3/10 \\
2/10 & 2/10 & 1/10 & 3/10 & 2/10 \\
0/10 & 0/10 & 0/10 & 2/10 & 8/10 \\
1/10 & 0/10 & 1/10 & 5/10 & 1/10 \\
\end{bmatrix}
\]

\[
D_3 = \begin{bmatrix}
0/10 & 0/10 & 2/10 & 3/10 & 5/10 \\
0/10 & 0/10 & 0/10 & 9/10 & 1/10 \\
0/10 & 0/10 & 1/10 & 6/10 & 3/10 \\
0/10 & 0/10 & 1/10 & 5/10 & 4/10 \\
\end{bmatrix}
\]

- **Confirm fuzzy relation matrix**: Conduct One-level fuzzy comprehensive assessment is conducted and the fuzzy relation matrix \( R = (R_2, R_3, R_3)^T \) is confirmed.

\[
R_2 = W^2 \cdot D_2 = \left\{ w_{21}, w_{22}, w_{23}, w_{24}, w_{25} \right\} \cdot D_2
\]

\[
= (0.2500, 0.1938, 0.3000, 0.2562) \cdot 
\begin{bmatrix}
0/10 & 0/10 & 3/10 & 4/10 & 3/10 \\
2/10 & 2/10 & 1/10 & 3/10 & 2/10 \\
0/10 & 0/10 & 0/10 & 2/10 & 8/10 \\
1/10 & 0/10 & 1/10 & 5/10 & 1/10 \\
\end{bmatrix}
\]

\[
= (0.0644, 0.0388, 0.1200, 0.2950, 0.4819)
\]

\[
R_3 = W^3 \cdot D_3
\]

\[
= (0.3967, 0.3471, 0.2562) \cdot 
\begin{bmatrix}
0/10 & 0/10 & 0/10 & 9/10 & 1/10 \\
1/10 & 1/10 & 0/10 & 3/10 & 5/10 \\
2/10 & 2/10 & 1/10 & 4/10 & 1/10 \\
\end{bmatrix}
\]

\[
= (0.0163, 0.0163, 0.0049, 0.0467, 0.0500)
\]

\[
= (0.2544, 0.2426, 0.2485, 0.2545) \cdot 
\begin{bmatrix}
0/10 & 0/10 & 2/10 & 3/10 & 5/10 \\
0/10 & 0/10 & 0/10 & 9/10 & 1/10 \\
0/10 & 0/10 & 1/10 & 6/10 & 3/10 \\
0/10 & 0/10 & 1/10 & 5/10 & 4/10 \\
\end{bmatrix}
\]

\[
= (0, 0, 0.1012, 0.5710, 0.3278)
\]

So the fuzzy relation matrix \( R \) can be obtained.

\[
R = (R_2, R_3, R_3)^T
\]

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

\[
E = W^T \cdot R = (0.1582, 0.2143, 0.1887, 0.2347, 0.2041) \cdot 
\begin{bmatrix}
0.0644 & 0.0388 & 0.1200 & 0.2950 & 0.4819 \\
0.0163 & 0.0163 & 0.0049 & 0.0467 & 0.0500 \\
0.2041 & 0.2347 & 0.1887 & 0.2143 & 0.1582 \\
\end{bmatrix}
\]

\[
= (0.0169, 0.0114, 0.0473, 0.1886, 0.1900)
\]

- **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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REFERENCES


