The fuzzy comprehensive evaluation of the highway emergency plan based on G1 method

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Abstract—The huge economic loss and serious social problems are brought to the country by the frequent happening of highway emergency. Therefore, how to avoid and reduce its impact is particularly important. Then, the emergency plan is an important part of the emergency rescue system, and the effective evaluation should be made for the highway emergency plan, which is of great importance to make fast and effective emergency response and reduce the impact of the emergency. In this paper, according to the characteristics of highway emergency plan and the related research, the evaluation index system is firstly established, then, G1 method is used in the calculation of the index weights, and thus the fuzzy evaluation method is cited to make a comprehensive evaluation on the emergency plan, which make subjective evaluation objective, so the accuracy of the evaluation have been improved. Finally an example is given to verify the proposed method, which provides the effective assessment to the highway emergency for reference.

keywords—highway emergency plan, G1 Method, fuzzy comprehensive evaluation

I. INTRODUCTION

According to the characteristics of the highway emergency plan, the corresponding index system with considering the impacting factors is established in this paper. And with the use of the combination of G1 method and fuzzy comprehensive evaluation method, the qualitative and quantitative analysis make the assessment results more reasonable and simple.

II. THE INDEX SYSTEM FOR EMERGENCY PLAN EVALUATION

Emergency plan is a complex disaster management system, which includes emergency response in three main areas that are before disaster, being disaster and after disaster. According to the emergency plan, the emergency response should be with the unified command and management to ensure that the situation can be effectively controlled in time and also that the civic life and property is safety when the incidents happen.

Taking the characteristics of the highway emergency plan into account, and according to the relevant academic research results, we believe that the analysis and evaluation for the railway emergency plans is more reasonable from the following perspectives, which include integrity, operability, effectiveness and reasonableness of the cost.

A. Integrity (Ob1)

The integrity means whether the elements of the emergency plan is comprehensive or not in the form, and in terms of content which means taking the emergency situation which may arise into account as comprehensively as possible. Then, the emergency plan can be established in line with the norms. For this, we selected indicators as so, which include the completeness of plan elements (OC11), the clarity for envisaged emergency (OC12), the completeness of rescue plan (OC13), and the completeness of the late disposal (OC14).

B. Operability (Ob2)

The operability means whether the emergency plan provides the reasonable steps based on the analysis for the specific incidents and also according to the actual ability of emergency support. The step should be practical in the condition of existing emergency response capability, and the connectivity between steps should be reasonable.

According to the characteristics of the highway emergency plan, we...
selected indicators as so, which include the traceability of emergency resources (OC31), the rationality of the equipped rescue workers (OC22), the clarity of response level (OC23), the clarity of information submitted (OC24), the rationality of rescue steps (OC25), the immediacy of emergency response (OC26), the reasonableness of the rescue equipment set (OC27).

C. Effectiveness (Ob3)

This indicator reflects the effect of the emergency events which can be achieved under certain time and certain resource constraints condition. In other words, the effectiveness reflects that the emergency plan effectively response to the emergencies to what extent under the limited conditions. The corresponding indicators include the effectiveness of early warning alarm (OC31), the effectiveness of emergency response (OC32), and the effectiveness of safeguards (OC33).

D. Reasonableness of the cost (Ob4)

The ideal implementation result of the emergency plan should not be completely regardless of the cost of investment to get, but should invest a reasonable cost to get. Therefore, the evaluation on the emergency plan should also evaluate the reasonableness of the cost on the disposal of the incidents. Under the premise of meeting the need for the emergency rescue, the cost should be of least. The corresponding indicators include the cost of emergency resources (OC41), the reasonableness of the emergency fees (OC42).

The index system is presented in Fig 1.

III. THE PROCEDURES AND PRINCIPLES OF FUZZY COMPREHENSIVE EVALUATION BASED ON G1 METHOD

Fuzzy comprehensive evaluation is a very effective multi-factor decision making method to make a comprehensive assessment of things that are influenced by many factors. But determining the weights of each index is the more difficult part, which is usually given by the experts based on the subjective experience. G1 method is a combination of the quantitative and qualitative method, with which the shortcomings of the AHP are avoided. It is not needed to construct matrix in the course of determining the weights of each index, and the consistency check in the AHP is also avoided in the method. Compared with the AHP, G1 method is more feasible and easy to use, in which the calculation is significantly reduced.

Therefore, the two methods are combined in the paper, which use G1 method to determine the weights of each index and fuzzy comprehensive evaluation method to evaluate the quality of the railway emergency plan. This will contribute to making the corresponding analysis and improvement on the highway emergency plan.

1) Establishing evaluation factors \( U \) : \( U = \{U_1, U_2, \cdots, U_k\} \), where \( \bigcup U_j = U \), \( \bigcap U_j = \Phi \), the criteria layer index \( U_{jm} \) is affected by specific indicators \( U_{ij} \), \( U_{ij} \cdots, U_{in} \), where \( U_i = (U_{i1}, U_{i2}, \cdots, U_{im}) \) (i = 1, 2, \cdots, k).

2) Determining the weight distribution of the criteria layer factors based on G1 method: \( W = (w_1, w_2, \cdots, w_k) \), where \( 0 < w_i \leq 1, \sum w_i = 1 \), and determining the weight distribution of each index \( U_j \), that \( w_i = (w_{i1}, w_{i2}, \cdots, w_{im}) \) (i = 1, 2, \cdots, k).

There are four steps in the G1 method[8]:

a) Determining the order relation: For the evaluation index set \( \{x_1, x_2, \cdots, x_m\} \), the order relation is established as the following steps: First, supposing an expert to select the indicator in the evaluation index set \( \{x_1, x_2, \cdots, x_m\} \), which is considered as the most important only one and is recorded as \( x^*_1 \). Second, supposing the expert to select the indicator in the remaining \( m-1 \) indicators, which is considered as the most important only one and is recorded as \( x^*_2 \). Then, after the selection, of which the number is m-1, the indicator is recorded as \( x^*_m \).

b) Determining the ratio of the importance between the index \( x^*_{k-1} \) and \( x^*_k \): According to the related information supposing that the experts give reasonable judgments of the ratio of the importance \( r_k \) between the index \( x^*_{k-1} \) and \( x^*_k \), based on a certain criteria (or goal) , therefore

\[
r_k = w_{k-1}/w_k, \quad k = m, m-1, \cdots, 3, 2
\]

Where \( w_i \) is the weight of the indicator \( x^*_i \), the value of \( r_k \) is shown in table 1.

c) Calculating the value of the weight: the weight of the indicator \( x^*_k \) is calculated as below,

\[
w_k = [1 + \sum_{i=2}^{m} r_{ij}]^{-1}, \quad w_{k-1} = r_k w_k, \quad k = m, m-1, \cdots, 3, 2
\]

d) Determining the weight of each index by the expert group: There are perhaps \( l, l_2, \cdots, l_z \) experts in the \( l \) experts,
who respectively give the same order relationship and the reasonable judgments of the ratio of the importance, where \(1 \leq \ell_j \leq \ell(s = 1, 2, \cdots, h)\), and \(\sum_{j=1}^{\ell} \ell_j = \ell_s \), so then
\[
w^j(s) = \frac{1}{\ell} \sum_{j=1}^{\ell} w^j(s), s = 1, 2, \cdots, h, j = 1, 2, \cdots, m
\]

Therefore, the weight of the evaluation index \(x_j\) is defined as:
\[
w_j = \frac{1}{\ell} w_j^1 + \frac{1}{\ell} w_j^2 + \cdots + \frac{1}{\ell} w_j^h, j = 1, 2, \cdots, m
\]

3) Determining the evaluation set: In this paper, in accordance with the corresponding evaluation factors level, the level of the highway emergency plan is divided into very good, better, generally, not very good, very bad, which is expressed as \(V = \{v_1, v_2, v_3, v_4, v_5\}\) = \{very good, better good, good, not very good, very bad\};

4) Establishing the fuzzy degree of membership matrix \(R_j\):
\[
R_j = \begin{bmatrix}
r_1 & r_2 & \cdots & r_m \\
r_1 & r_2 & \cdots & r_m \\
\vdots & \vdots & \ddots & \vdots \\
r_1 & r_2 & \cdots & r_m
\end{bmatrix}
\]

Which is the separate evaluation on the factor \(U_j\), and with \(r_{jy}\) presenting the grade of membership of factor \(x\) aiming at comment \(y\), which is generally be normalized, that \(\sum_{j=1}^{\ell} r_{jy} = 1\)

5) Establishing the fuzzy comprehensive evaluation matrix \(R\) : where \(R = [B_1, B_2, \cdots, B_T]^T\), and \(B_i = w_i \times R_i\) is the evaluation vector for each factor.

6) Establishing the overall evaluation vector: \(C = W \cdot R\) Then make an evaluation on the level of the emergency plan in accordance with the principle of the maximum degree of membership.

7) Calculating the evaluation score for emergency plan: The score of the level for the emergency plan is set as \(\{5, 4, 3, 2, 1\}\), which is correspond with the evaluation set \{very good, better good, good, not very good, very bad\}. Then, according to the overall evaluation vector \(C\), the evaluation score for emergency plan can be got.

<table>
<thead>
<tr>
<th>(r_j)</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>the same importance</td>
</tr>
<tr>
<td>1.1</td>
<td>between little more importance and same importance</td>
</tr>
<tr>
<td>1.2</td>
<td>little more importance</td>
</tr>
<tr>
<td>1.3</td>
<td>between more importance and little more importance</td>
</tr>
<tr>
<td>1.4</td>
<td>more importance</td>
</tr>
<tr>
<td>1.5</td>
<td>between much more importance and more importance</td>
</tr>
</tbody>
</table>

### IV. Example

Taking the emergency plan P1 that 'The emergency plan of highway accident' as the example, in accordance with the principles and procedures described above, and using the index system shown in Figure 1, the evaluation is made on the level of the emergency plan.

1) Determination of the weights: According to the above steps, the evaluation is made by the experts on the relative importance of each index to sort the scoring, and then based on G1 method to obtain the weight value of each index, seeing Table 2.

2) The fuzzy degree of membership matrix be got: which is through the evaluation by the experts on the index above and the corresponding comment set.

3) Making the fuzzy operators: Between the weight distribution matrix and the fuzzy evaluation matrix, the fuzzy operators are made, then the fuzzy comprehensive evaluation matrix can be got.

First, calculating the evaluation vector based on MATLAB
\[
B_i = \omega_i \cdot R_i = (0.2415 0.3285 0.2980 0.0892 0.0428)'
\]
\[
B_2 = \omega_2 \cdot R_2 = (0.2348 0.3295 0.2127 0.1466 0.0764)'
\]
\[
B_3 = w_1 \cdot R_1 = (0.1515 0.3200 0.2485 0.1800 0.0485)'
\]
\[
B_4 = \omega_4 \cdot R_4 = (0.3272 0.2546 0.2637 0.1000 0.0546)
\]

##### Table I. The Weights Of The Index

<table>
<thead>
<tr>
<th>The index</th>
<th>The weights of each index</th>
</tr>
</thead>
<tbody>
<tr>
<td>OC11</td>
<td>0.1435</td>
</tr>
<tr>
<td>OC12</td>
<td>0.2063</td>
</tr>
<tr>
<td>OC13</td>
<td>0.4276</td>
</tr>
<tr>
<td>OC14</td>
<td>0.1606</td>
</tr>
<tr>
<td>OC15</td>
<td>0.1265</td>
</tr>
<tr>
<td>OC21</td>
<td>0.1657</td>
</tr>
<tr>
<td>OC22</td>
<td>0.2245</td>
</tr>
<tr>
<td>OC23</td>
<td>0.1152</td>
</tr>
<tr>
<td>OC24</td>
<td>0.1462</td>
</tr>
<tr>
<td>OC25</td>
<td>0.1346</td>
</tr>
<tr>
<td>OC26</td>
<td>0.0873</td>
</tr>
<tr>
<td>OC27</td>
<td>0.5288</td>
</tr>
</tbody>
</table>

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Then, the fuzzy Comprehensive Evaluation matrix $R$ is got based on $R = (B_1, B_2, B_3, B_4)^T$
$$
\begin{bmatrix}
0.2415 & 0.3285 & 0.2980 & 0.0892 & 0.0428 \\
0.2348 & 0.3295 & 0.2127 & 0.1466 & 0.0764 \\
0.1515 & 0.3200 & 0.2485 & 0.1800 & 0.0485 \\
0.3272 & 0.2546 & 0.2637 & 0.1000 & 0.0546 
\end{bmatrix}
$$

Then, according to $W = (0.2266, 0.5288, 0.1859, 0.0587)$, the overall evaluation vector is got.

$$
C = W \cdot R = (0.2263, 0.3231, 0.2417, 0.1371, 0.0623)
$$

Then, the evaluation score for emergency plan can be calculated as so
$$
0.2263 \times 5 + 0.3231 \times 4 + 0.2417 \times 3 + 0.1371 \times 2 + 0.0623 \times 1 = 3.4861
$$

From the calculating results, the emergency plan were grade "better good" with the greatest degree of membership, so the plan is graded as better good in accordance with the principle of maximum degree of membership.

V. CONCLUSION

The highway emergency plan is the basis for taking urgent action and relief measures when the accidents happen, so how to make an effective evaluation on the reasonableness of the highway emergency plan is very important. In this paper, we make an evaluation on the index system with the combination of G1 method and fuzzy comprehensive evaluation method, which not only combined quantitatively and qualitatively but also make subjective evaluation objective, so the accuracy of the evaluation have been improved. Fuzzy comprehensive evaluation can only give a vague assessment of the results, and it is not an accurate assessment of the inadequacies of the emergency plan. So, according to the implementation and drill for the emergency plan, the evaluation results should be made the corresponding improvements.

ACKNOWLEDGMENT

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REFERENCES