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Classification Model of Traffic Emergency Response to Urban Emergency

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Abstract: In order to respond to emergency and use emergency resources effectively by traffic department, a quantified classification model of traffic emergency response was developed. First, the evaluation index system was established from the two aspects: urgency of traffic response and difficulty in traffic rescue. Next, the weights of factors for each level were determined using fuzzy analytic hierarchy process. Then, the grade of traffic emergency response was determined using a multi-level fuzzy comprehensive evaluation. Finally, an example was used to validate the model. The results show that combined application between fuzzy analytic hierarchy process and fuzzy comprehensive method effectively computes the grade of traffic response, and conveniently considers various complex factors of treatments of urban emergency. *Copyright © 2012 IFSA.*

Keywords: Urban emergency, Traffic emergency, Response classification, Fuzzy analytic hierarchy process, Fuzzy comprehensive evaluation.

1. Introduction

Traffic plays key role in treatment of urban emergency, either in evacuation or in rescue materials transportation. It is very significant to deal with emergency and reduce loss whether transportation department can respond rapidly and implement effective emergency plan after emergency. Determination the grade of traffic emergency response is the premise of making pre-plan. Only if plans

are made according to corresponding grade, the emergency resources can be use effectively and inadequate materials or waste can be avoided.

At present, most studies pay attention on grading of emergency at home and abroad [1-8]. There are few researches on classification of traffic emergency response. In addition, the previous researches are qualitative, lacking of quantitative analysis. It is difficult to accurately quantify the classification of traffic response and provide practical guidance and scientific issues.

Based on this, this paper puts forward a quantitative classification model of traffic emergency response based on combination of fuzzy analytic hierarchy process and fuzzy comprehensive evaluation, which has important theory significance and practical value for treatment emergency.

2. Structure of Classification Model

2.1. Determination of Evaluation Set

Overall Emergency Preplan for National Sudden Public Incidents State [9] was issued by China's State Council which prescribed that every type of emergency can be divided four-grade according to the character, severity, controllability and the extent. Based on it, traffic emergency response can be divided into four grades, namely, specifically (*i*), major (*ii*), a (*iii*), general (*iv*).

2.2. Establishment of Evaluation Index System

There are many factors which are related with grading of traffic emergency response to urban emergency, but the principal influence factors are urgency of traffic response and difficulty in traffic rescue after emergency. The degree of urgency of traffic response mainly embodies two aspects: severity of incident and impact on traffic, and the more the urgency, the higher the grade. The degree of difficulty in traffic rescue is the convenient degree provided by traffic system in the rescue, which is related with traffic situation, traffic facilities and traffic environment around incident site, and the more the difficulty, the higher the grade. The specific index system is shown in Fig. 1 [10].

2.3. Calculation of Weight of Index

Because of different relative significance between indexes for the upper index, each index should be given a weight Wi to reflect this difference. An analytic hierarchy process is usually applied in determination of weight, but in the traditional formulation of the AHP, human's judgments are represented as crisp values. However, in many practical cases the human preference model is uncertain and decision makers might be reluctant or unable to assign crisp values to the comparison judgments [11]. Having to use crisp values is one of the problematic points in the crisp evaluation process [12]. And this method is often criticized due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pair-wise comparison process [13]. To overcome all these shortcomings, FAHP was used for this model.

A triangular fuzzy number $\tilde{A}$ is defined by three real numbers $a \leq b \leq c$, and characterized by a linear piecewise continuous membership function $\tilde{A}(x)$ of the type [14].

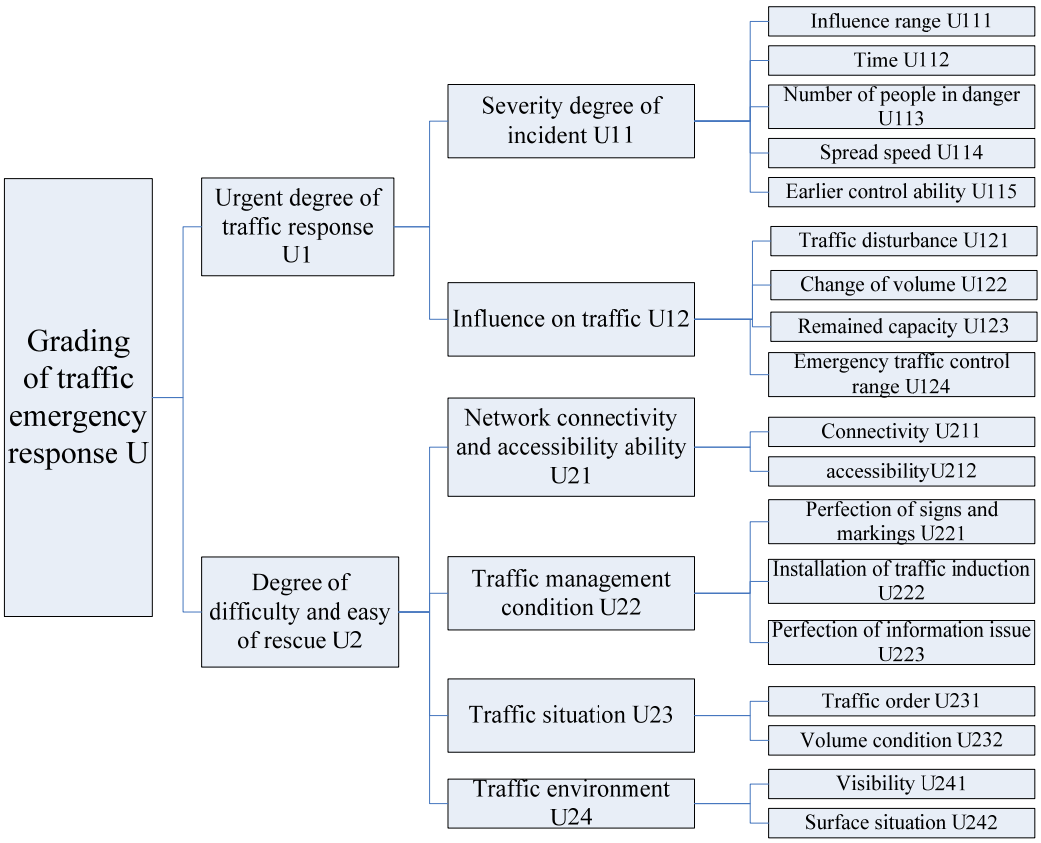

Fig. 1. Index system of grading of traffic emergency response.

$$\tilde{A}(x) = \begin{cases} \dfrac{x-c}{a-c}, c \le x \le a \\ \dfrac{x-b}{a-b}, a \le x \le b \\ 0, otherwise \end{cases}, \tag{1}$$

where a is the most possible value of the fuzzy number $\tilde{A}$, and c and b are lower and upper bounds, respectively.

Firstly, the fuzzy judgment matrix is established based on triangular fuzzy number using pairing comparison and 1-9 scaling method developed by Thomas L. Saaty [15]. For each paring comparison, there are several triangular fuzzy numbers given by several experts, such as $\tilde{A}_{ij}^{(1)}$, $\tilde{A}_{ij}^{(2)}$ ... $\tilde{A}_{ij}^{(k)}$, and $\tilde{A}_{ij}^{(1)} = (c_{ij}^{(1)}, a_{ij}^{(1)}, b_{ij}^{(1)})$. Then, these numbers are integrated by equation (2) [16].

$$A_{ij} = (c_{ij}, a_{ij}, b_{ij}) \text{ and } \begin{cases} c_{ij} = \min(c_{ij}^{(1)}, c_{ij}^{(2)}, \cdots c_{ij}^{(n)}) \\ a_{ij} = \sqrt[n]{(\prod_{k=1}^{n} a_{ij}^{(k)})} \\ b_{ij} = \max(b_{ij}^{(1)}, b_{ij}^{(2)}, \cdots b_{ij}^{(n)}) \end{cases}, \tag{2}$$

where, $c_{ij}^{(k)}$ is the pessimistic assessment on relative significance between factor i and j for k^{th} expert; $a_{ij}^{(k)}$ is the average assessment on relative significance between factor i and j for k^{th} expert; $b_{ij}^{(k)}$ is the optimistic assessment on relative significance between factor i and j for k^{th} expert.

Secondly, the value of fuzzy synthetic extent with respect to the i^{th} factor is calculated by the following equations [17-18].

$$S_i \approx \sum_{j=1}^{m} \widetilde{A}_{ij} \otimes [\sum_{i=1}^{n}\sum_{j=1}^{m} \widetilde{A}_{ij}]^{-1}, \tag{3}$$

$$\sum_{j=1}^{m} \widetilde{A}_{ij} = (\sum_{j=1}^{m} c_j, \sum_{j=1}^{m} a_j, \sum_{j=1}^{m} b_j), \tag{4}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} \widetilde{A}_{ij} = (\sum_{i=1}^{n} c_i, \sum_{i=1}^{n} a_i, \sum_{i=1}^{n} b_i), \tag{5}$$

$$[\sum_{i=1}^{n}\sum_{j=1}^{m} \widetilde{A}_{ij}]^{-1} = (\frac{1}{\sum_{i=1}^{n} b_i}, \frac{1}{\sum_{i=1}^{n} a_i}, \frac{1}{\sum_{i=1}^{n} c_i}) \tag{6}$$

Thirdly, the weights of indexes can be calculated by the following steps.

Step 1: the degree of possibility of $\widetilde{A}_2 = (c_2, a_2, b_2) \geq \widetilde{A}_1 = (c_1, a_1, b_1)$ is defined as:

$$V(\widetilde{A}_2 \geq \widetilde{A}_1) = hgt(\widetilde{A}_1 \cap \widetilde{A}_2) = \begin{cases} 1, a_2 \geq a_1 \\ 0, c_1 \geq b_2 \\ \dfrac{c_1 - b_2}{(a_2 - b_2) - (a_1 - c_1)}, otherwise \end{cases}, \tag{7}$$

Step 2: the degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $\widetilde{A}_i (i = 1,2,\cdots k)$ can be defined by:

$$V(\widetilde{A} \geq \widetilde{A}_1, \widetilde{A}_2, \cdots \widetilde{A}_k) = \min V(\widetilde{A} \geq \widetilde{A}_i), i = 1,2,\cdots k, \tag{8}$$

Step 3: $W' = (\min V(S_1 \geq S_k), \min V(S_2 \geq S_k), \cdots \min V(S_n \geq S_k))^T$ is the weight vector for k=1, 2...n. After normalization, the normalized weight vector can be calculated as W.

2.4. Fuzzy Evaluation of Single Factor

After determination of weights of each factors, evaluation object will be quantified, namely, the membership degree that evaluation object belongs to each grade in terms of each single factor will be determined, thus, the fuzzy relationship matrix is obtained[19].

$$R = \begin{Bmatrix} R/U1 \\ R/U2 \\ \vdots \\ R/Um \end{Bmatrix} = \begin{Bmatrix} r_{11} & r_{12} & \cdots & r_{1k} \\ r_{21} & r_{22} & \cdots & r_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mk} \end{Bmatrix}_{m \times k}, \tag{9}$$

The element r_{mk} in Row m /Column k in matrix R is the membership degree that evaluation object is evaluated V_k class in terms of single factor U_m. The gravity method is used to determine the membership function [20], namely, $r_{mk}=d_j/d$, d is the total number of experts; d_j is the number of experts who evaluate the index U_m into V_k grade; m denotes the number of indexes, k expresses the grade (k=4). The evaluation standard of each factor is shown in Table 1.

Table 1. Evaluation standard of each factor.

Factors	Evaluation grade			
	I	**II**	**III**	**IV**
Event time	Peak time on day	After midnight	Off-peak time on day	Earlier night
Duration time/h	≥24	[12, 24]	[3, 12]	<3
Influence range (radius/km) (hazardous materials)	≥25	[10, 25]	[4, 10]	<4
Influence range (radius/m) (fire or blast)	≥5000	[1000, 5000]	[500, 1000]	<500
Number of people in danger	≥1000	[500, 1000]	[100, 500]	<100
Spread speed	very fast	fast	general	slow
Control ability	very weak	weak	strong	very strong
Degree of traffic disturbance	traffic disruption	serious congestion	congestion	driving slowly
Change of volume(ratio of increased volume and initial volume)	≥ 80 %	[50 %, 80 %]	[20 %, 50 %]	< 20 %
Remained lane capacity(ratio of remained lane number and initial lane number)	< 20 %	[20 %, 50 %]	[50 %, 80 %]	≥ 80 %
Emergency traffic control range	total area	area enclosed by next adjacent road	area enclosed by adjacent road	main rescue road
Network connectivity	bad	general	well	very well
Network accessibility	very low	low	high	very high
Perfection of signs and markings	not perfect	more perfect	perfect	very perfect
Installation of traffic induction	information in delay	rather timely information	timely information	accurate and timely information
Other information issue equipments	issue pattern is less than 2	issue pattern is 3	issue pattern is 4	issue pattern is more than 5
Traffic order	extraordinary disorder	disorder	rather disorder	General
Traffic flow situation	super saturation	saturation	high volume	Few volume
Visibility（m）	<50	[50, 100]	[100, 200]	≥2 00
Surface condition	snow or frozen	surface water	wet	dry

2.5. Multi-grade Fuzzy Comprehensive Evaluations

The index system is established in three grades in above, so the three-grade fuzzy comprehensive evaluation method is used in the model.

1) Firstly evaluation: it is a fuzzy evaluation of indexes such as severity degree of incident and influence on traffic etc.

First, the membership of tertiary indexes can be gained by evaluation of single factor, so the evaluation vector is expressed by:

$$R_{sim} = [r_{sim1}, r_{sim2}, r_{sim3}, r_{sim4}], \tag{10}$$

where r_{simj} is the membership degree of grade V_j that evaluation object is evaluated; s is the number of first class index (s=1, 2); i is the number of secondary index under the same first class index i=1, 2 ...p, (p=2, 4); m is the number of tertiary index under the same secondary index m=1, 2 ...n, (n=2, 3, 4, 5).

Then the fuzzy comprehensive evaluation matrix is:

$$R_{si} = \begin{Bmatrix} r_{si11} & r_{si12} & r_{si13} & r_{si14} \\ r_{si21} & r_{si22} & r_{si23} & r_{si24} \\ \vdots & \vdots & \vdots & \vdots \\ r_{sim1} & r_{sim2} & r_{sim3} & r_{sim4} \end{Bmatrix}, \tag{11}$$

So, the fuzzy vector of the secondary indexes can be obtained by fuzzy calculation of weight vector of influence factors and evaluation vector of each factor. (Equation (12)).

$$W_{si} \circ R_{si} = (W_{si1}, W_{si2}, \cdots, W_{sim}) \begin{Bmatrix} r_{si11} & r_{si12} & r_{si13} & r_{si14} \\ r_{si21} & r_{si22} & r_{si23} & r_{si24} \\ \vdots & \vdots & \vdots & \vdots \\ r_{sim1} & r_{sim2} & r_{sim3} & r_{sim4} \end{Bmatrix} = (b_{si1}, b_{si2}, b_{si3}, b_{si4}) = B_{si}, \tag{12}$$

where w_{sim}_is the weight of tertiary indexes.

2) Secondly evaluation: it is a fuzzy evaluation of two indexes such as urgent degree of traffic response and difficult degree of traffic rescue.

Likely as the firstly evaluation, the secondly evaluation is done by fuzzy calculation of weight vector of lower indexes and evaluation vector obtained by firstly evaluation. (Equation (13))

$$W_s \circ R_s = (W_{s1}, W_{s2}, \cdots, W_{si}) \begin{Bmatrix} b_{s11} & b_{s12} & b_{s13} & b_{s14} \\ b_{s21} & b_{s22} & b_{s23} & b_{s24} \\ \vdots & \vdots & \vdots & \vdots \\ b_{si1} & b_{si2} & b_{si3} & b_{si4} \end{Bmatrix} = (b_{s1}, b_{s2}, b_{s3}, b_{s4}) = B_s, \tag{13}$$

where w_{si} is the weight of secondary indexes.

3) Thirdly evaluation: it is a comprehensive evaluation of grading of traffic emergency response that is done by fuzzy calculation of weight vector of urgent degree of traffic response and difficult degree of traffic rescue and evaluation vector is obtained by secondly evaluation. (Equation (14))

$$W \circ R = (W_1, W_2) \begin{Bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \end{Bmatrix} = (b_1, b_2, b_3, b_4) = B, \tag{14}$$

2.6. Analysis of Result

According to the principle of maximum membership degree, the maximum value of thirdly evaluation vector is selected and the evaluation grade is obtained.

3. Case Analyses

3.1. Background of Incident

At 8:45 am, on July 12, 2011, there was a fire in a factory which happened in technical industry park in Wuhan economic development zone. The site of the fire is a warehouse in the first floor, and office and staff dormitory are in the second floor. When the fire broke up, most of people could escape except about ten people including two children. The burned areas are 1000 m^2. Many plastic products that would release toxic gas after combustion were in the warehouse. At that time, the traffic situation was well and road traffic facilities were perfect.

3.2. Judgment of Grade

3.2.1. Calculation of Weight of Index

According the above method of calculation of weights based on FAHP, the weights of each index are as follows.

1) The weight of tertiary indexes:

$W_{11} = (0.071,0.056,0.458,0.251,0.164)$
$W_{12} = (0.181,0.461,0.278,0.080)$
$W_{21} = (0.488,0.512)$
$W_{22} = (0.184,0.615,0.201)$
$W_{23} = (0.316,0.684)$
$W_{24} = (0.3,0.7)$

2) The weight of secondary indexes:

$W_1 = (0.792,0.208)$
$W_2 = (0.436,0.021,0.338,0.205)$

3) The weight of first class indexes:

$W = (0.637 \quad 0.363)$

3.2.2. Fuzzy Comprehensive Evaluation and Judgment of Grade

1) Evaluation of single factors

The evaluation vector matrixes are gotten through analyzing each factor.

$$R_{11}=\begin{Bmatrix}0.8 & 0.2 & 0 & 0\\ 0 & 0.4 & 0.6 & 0\\ 0 & 0 & 0.7 & 0.3\\ 1 & 0 & 0 & 0\\ 0.9 & 0.1 & 0 & 0\end{Bmatrix} \quad R_{12}=\begin{Bmatrix}0 & 0 & 0.1 & 0.9\\ 0 & 0 & 0.6 & 0.4\\ 0 & 0 & 0.1 & 0.9\\ 0 & 0 & 0.2 & 0.8\end{Bmatrix} \quad R_{21}=\begin{Bmatrix}0 & 0 & 0.2 & 0.8\\ 0 & 0 & 0 & 1\end{Bmatrix}$$

$$R_{22}=\begin{Bmatrix}0 & 0 & 0.3 & 0.7\\ 0.2 & 0.8 & 0 & 0\\ 0 & 0.6 & 0.4 & 0\end{Bmatrix} \quad R_{23}=\begin{Bmatrix}0 & 0 & 0.2 & 0.8\\ 0 & 0 & 0 & 1\end{Bmatrix} \quad R_{24}=\begin{Bmatrix}0 & 0 & 0 & 1\\ 0 & 0 & 0 & 1\end{Bmatrix}$$

2) Firstly evaluation

Firstly evaluation vectors are gotten according to evaluation vector matrixes of single factors and their weights.

Evaluation vectors of severity degree of incident:

$$B_{11}=(0.4554 \quad 0.0530 \quad 0.3542 \quad 0.1374)$$

Evaluation vectors of impact on traffic by incident:

$$B_{12}=(0 \quad 0 \quad 0.3385 \quad 0.6615)$$

Evaluation vectors of access capability of road network:

$$B_{21}=(0 \quad 0 \quad 0.0976 \quad 0.9024)$$

Evaluation vectors of traffic management condition:

$$B_{22}=(0.1230 \quad 0.6126 \quad 0.1356 \quad 0.1288)$$

Evaluation vectors of traffic situation:

$$B_{23}=(0 \quad 0 \quad 0.0632 \quad 0.9365)$$

Evaluation vectors of traffic environment:

$$B_{24}=(0 \quad 0 \quad 0 \quad 1)$$

3) Secondly evaluation

Evaluation vectors of urgent degree of traffic response:

$$B_{1}=(0.3607 \quad 0.0420 \quad 0.3509 \quad 0.2464)$$

Evaluation vectors of difficult degree of traffic rescue:

$$B_{2}==(0.0026 \quad 0.0129 \quad 0.0668 \quad 0.9177)$$

4) Thirdly evaluation

Comprehensive evaluation vectors of grading of traffic emergency response:

$$B=(0.2307 \quad 0.0315 \quad 0.2477 \quad 0.4901)$$

4. Conclusions

Determination of grade of traffic emergency responding is the important premise on response rapidly and allocating resource effectively by traffic department and improving rescue efficiency. In this paper, evaluation index system was established based on urgent degree of traffic response and difficult degree of traffic rescue, and the weights of indexes are computed by FAHP. Finally, classification model of traffic emergency response was proposed using fuzzy comprehensive evaluation, which will provide certain basis for making traffic emergency plan.

However, the grade of traffic emergency response may change after implementing preplan, which belongs to dynamic grading. How to consider the dynamic relationship between preplan and grading of traffic emergency response will be a major focus for future research. In addition, the rationality of judgment criteria of each factors needs to be verified.

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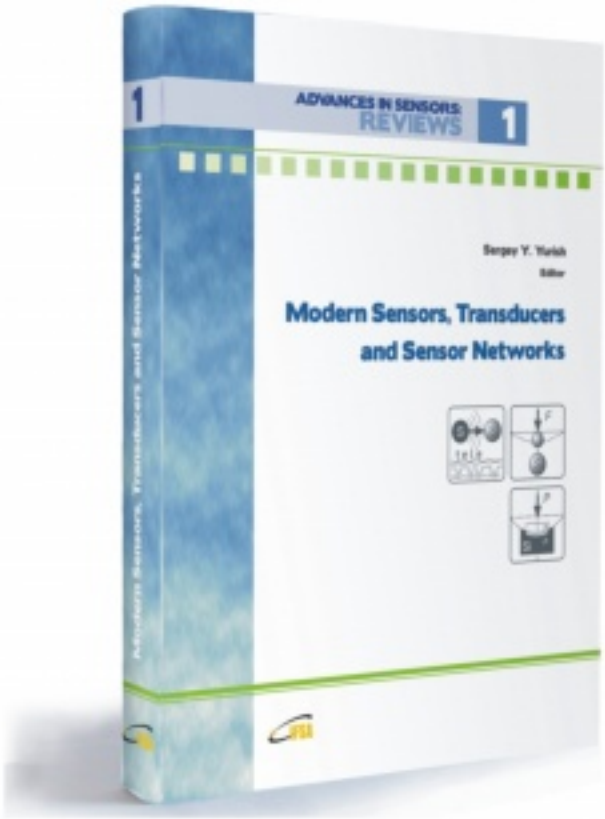

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