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Research Article

A New Early Warning Evaluation Method and Decision Mechanism for Urban Significant Emergency in Uncertain Environment

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Abstract: This study presents a new early warning evaluating method and decision mechanism for urban emergency in which the risk factors are assessed by fuzzy numbers. By using the fuzzy preference relation matrix and the extended fuzzy AHP, the relative weight of each risk factor can be estimated. Then we evaluate the total fuzzy risk value by aggregating the severity of loss of risk factor and the relative weight of risk factor. According to the similarity between the fuzzy comprehensive risk value and the pre-established risk grade, the early warning grade of urban significant emergency can be determined for urgent emergency decision-making.

Keywords: Decision making, risk evaluation, similarity measure, urban emergency, warning grade

INTRODUCTION

With the development and expansion of city, the frequency and strength of significant emergencies are increasing in many cities. So, urban significant emergency index analysis and early warning become very important research issues in emergency management. As is well known, the urban emergency inevitably affects many aspects of urban including urban economy recession, safety of environment and property and health condition. In the past decades, the scholars proposed some methods of index selecting and weighting for emergency (Zhang, 2008). Some researchers have also proposed many urgent decision making approaches for urban significant emergency (He and Lu, 2010; He and Li, 2012; Zhao, 2009; Zhou and Zhang, 2006; Gao, 2010). Also some early warning management methods for urban incidents have been introduced (Ye, 2007; Zhi *et al*., 2009; Tang, 2008; Yang and Ding, 2009; Lang, 2011; Wang, 2005; Ma *et al*., 2006; Wen and Bian, 2006). However, most of the existing early warning mechanisms and decision methods can only deal with the urban emergency under precise condition. In fact, due to the increasing complexity of the socio-economic environment and the lack of knowledge about the problem domain, most of the real-world problems, such as urban emergency decision analysis and emergency warning degree evaluation, are involved variety of uncertainty like fuzzy number (Deng *et al*., 2004) and fuzzy linguistic value (Rodriguez *et al*., 2012). Especially, in the warning degree evaluation process of urban significant emergency it will inevitably involve some fuzzy factors, including the serious economy depression, the wicked environment destroy, the improper emergency broadcasting, the enormous casualties and the critical traffic jam, as well as the inadequate emergency rescue facilities. Also, the values of the above risk factors are easily expressed by fuzzy linguistic terms.

Moreover, the unexpected and uncontrolled uncertain risks easily incur the urban significant emergency. So, in order to decrease the possibility of urban significant emergency, there is much need to analyze and control the risk of urban significant emergency. Also, it is a necessitous task for urban government department decision-maker to adopt the corresponding strategy to reduce the occurrence of significant emergency in some urban zone according to the evaluated fuzzy comprehensive risk value.

Recently, many researchers have studied the risk analysis of emergency in Liu and Yuan (2006), Wang and Lin (2009), Xiao (2012) and Ye and She (2011), but the fuzzy risk factor was not considered. Although the fuzzy entropy and comprehensive judgment method (Zhong and Xie, 2011) was used to calculate the occurring probability of risk, it has some drawbacks since it is based on traditional Shannon entropy. And the fuzzy comprehensive risk judgment of HR outsourcing was discussed (Li, 2007), but the method is unable to determine the accurate risk grade. In fact, most of the existing fuzzy risk computing methods can not effectively cope with the risk evaluating and warning degree determining involved fuzzy risk factors. Thus, in this study we aim to propose a new fuzzy risk

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computing and warning degree evaluation approach for urban emergency in uncertain environment. As we are aware, the warning grade of urban emergency is influenced by the severity of risk factor and the relative weight of risk factor. To obtain the relative importance of each fuzzy risk factor, we will develop an extended fuzzy AHP method in this study.

PRELIMINARIES

Fuzzy Set (FS) first introduced by Zadeh is a useful generalization of the ordinary set, which has been proved to be more suitable way for dealing with vagueness and uncertainty. Particularly, information entropy (Kosko, 1986; Zeng and Guo, 2008; Zhang and Jiang, 2010), similarity measure and distance measure of FSs play very important roles in the application fields like pattern recognition (Li and Cheng, 2002; Zhang and Jiang, 2008), risk analysis (Chen and Chen, 2007) and decision-making (Wang, 2012).

Definition 1: A fuzzy set $\alpha = (\alpha_1,\alpha_2,\alpha_3)$ in the universe of discourse X in R is called a triangular fuzzy number if its membership function can be expressed as the following form.

$$f_{\tilde{a}}(x) = \begin{cases} 0, & x \le a_1 \, or \quad x > a_3 \\ f_{\tilde{a}}^{L}(x) = \dfrac{x - a_1}{a_2 - a_1}, & a_1 < x \le a_2 \\ f_{\tilde{a}}^{U}(x) = \dfrac{a_3 - x}{a_3 - a_2}, & a_2 < x \le a_3 \end{cases}$$

Definition 2: Let $\tilde{a} = (\alpha_1, \alpha_2, \alpha_3)$, $\tilde{b} = (b_1, b_2, b_3)$ be two triangular fuzzy numbers, some basic operations between them are given as follows:

$$\tilde{a} + \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \tag{1}$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3) \otimes (b_1, b_2, b_3) = (l, m, u)$$

where,

$$l = \min(a_1 b_1, a_1 b_3, a_3 b_1, a_3 b_3)$$

$$m = a_2 b_2 ,\ u = \max(a_1 b_1, a_1 b_3, a_3 b_1, a_3 b_3)$$

Remark 1: If α_1, α_2, α_3, b_1, b_2, $b_3 > 0$ and $k > 0$, $w > 0$, then:

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3) \otimes (b_1, b_2, b_3)$$

$$= (a_1 b_1, a_2 b_2, a_3 b_3) \tag{2}$$

$$1 / \tilde{b} = 1 / (b_1, b_2, b_3) = (\frac{1}{b_3}, \frac{1}{b_2}, \frac{1}{b_1})$$

$$\tilde{a}^k = (a_1^k, a_2^k, a_3^k)$$

$$w\tilde{a} = (wa_1, wa_2, wa_3)$$

Definition 3: The similarity measure between any two triangular fuzzy numbers $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ is defined as:

$$S(\tilde{a}, \tilde{b}) = \frac{1}{1 + \left| p(\tilde{a}) - p(\tilde{b}) \right|} \tag{3}$$

where,

$$p(\tilde{a}) = (a_1 + 4a_2 + a_3) / 6 \quad p(\tilde{b}) = (b_1 + 4b_2 + b_3) / 6$$

are the graded mean integration representations of $\tilde{a}$ and $\tilde{b}$, respectively.

Definition 4: Let $C = \{c_1, c_2, \ldots, c_k\}$ be the early warning index set of urban significant emergency and $(g_{ij})_{k\times k}$ be the pair-wise comparison fuzzy preference matrix, where g_{ij} represents the fuzzy preference degree of index c_i over index c_j, $g_{ij} = 1/g_{ij}$. The fuzzy weight of each warning index can be defined by

$$w_i = \frac{(\otimes_{j=1}^{k} g_{ij})^{1/k}}{\sum_{i=1}^{k} (\otimes_{j=1}^{k} g_{ij})^{1/k}} . \tag{4}$$

EARLY WARNING EVALUATION AND DECISION FOR URBAN EMERGENCY

As we know, the urban significant emergency will possibly face to many kinds of risk factors with different probabilities. Especially in the uncertain emergency management environment, the accurate value of risk factor is difficult to measure, but by means of fuzzy linguistic term, we can conveniently represent the relative weight and the severity of loss of each risk factor. Through fuzzy risk analysis method, we can correctly estimate the risk grade of urban significant emergency. Generally, by questionnaire survey and statistical analysis from some field experts and emergency managers we can easily get some important risk factors that incur urban significant emergency, including the economy risk, the environment risk, the humanity risk and the traffic jam risk, public health risk, as well as the emergency facility risk, etc. Suppose the set of all risk factors of urban significant emergency is denoted by U. Generally, the risk factor is a fuzzy concept, for example, serious economic recession,

Table 1: Linguistic terms for rating the severity of loss of the risk factor in urban significant emergency

Linguistic terms	Fuzzy numbers
Critical	(0.9, 1.0, 1.0)
Serious	(0.6, 0.7, 0.8)
Medium	(0.4, 0.5, 0.6)
Weak	(0.3, 0.4, 0.5)
Neglectful	(0.0, 0.1, 0.2)

Table 2: Linguistic terms for comparing the importance degree of warning risk factors

Intensity of importance	Definition of grade	Fuzzy numbers
9	Extremely strong importance	(9/2,5,11/2)
7	Very strong importance	(7/2,4,9/2)
5	Strong importance	(5/2,3,7/2)
3	Moderate importance	(3/2,2,5/2)
2	Just equal importance	(1, 1,2)
1	Equal importance	(1,1,1)

Table 3: 5-Linguistic terms for rating warning grade of urban significant emergency

Linguistic terms	Fuzzy numbers
Extremely High (EH)	(0.9, 1, 1)
Very High (VH)	(0.7,0.8,0.9)
Fairly High (FH)	(0.5,0.6,0.8)
Medium (M)	(0.2,0.4,0.5)
Low (L)	(0.1,0.2,0.3)

severe environment pollution, wicked emergency broadcasting, bad public health and incomplete emergency facility and so on. As we are aware, the accurate values of the severity of loss and the relative importance degree of each fuzzy risk factor are difficult to measure in uncertain setting, but easily assessed by fuzzy language terms, like R = {Critical, Serious, Medium, Weak, Neglectful} and W = {Extremely strong importance, Very strong importance, Strong importance, Moderate importance, Just Equal importance, Equal importance}.

In order to simplify assessing the severity of loss and the importance degree of each risk factor in urban significant emergency, some unified sets of linguistic terms are predetermined as in Table 1 and 2.

In order to determine the risk warning grade of urban emergency and provide early warning in time, we set five different risk grades of urban significant emergency by fuzzy linguistic terms as in Table 3.

Here, we denote all the five risk grades by the set G = {G_1 (EH), G_2 (VH), G_3 (FH), G_4 (M), G_5 (L)}. Based on the previous risk analysis, here we give the fuzzy comprehensive risk evaluation process for urban significant emergency involved fuzzy risk evaluation value in uncertain environment.

Step 1: Let U be the set of all fuzzy risk factors $\{u_1, u_2, \dots, u_n\}$ of urban significant emergency and by pair-wise comparison between warning indexes we construct the fuzzy comparison preference matrix $\tilde{D} = (\tilde{r}_{ij})_{n \times n}$ where $\tilde{r}_{ij} = (l_{r_{ij}}, m_{r_{ij}}, u_{r_{ij}})$ is the fuzzy preference degree of risk factor u_i over risk factor u_j, which can be given as a fuzzy number by the knowledge of field experts and Table 2.

Table 4: Decision mechanism for the corresponding early warning grade of urban emergency

Early warning grade	Emergency decision mechanism
G_1 (extremely high marked by red alarm)	Mobilize ambulance and transport urgent needs
G_2 (very high marked by orange alarm)	Coordinate emergency management among different municipal zones and districts
G_3 (fairly high marked by yellow alarm)	Monitor the safety hazard in some important urban areas and estimate the public interest losses of intimidate
G_4 (medium marked by blue alarm)	Examine the procedures and facilities for coping with emergency and notify citizens to take some necessary safety measures
G_5 (low marked by green alarm)	Keep education and training in safety and get ready for dealing with possible emergency

Step 2: By using formula (4), we can compute the relative weight vector of all the risk factors in the uncertain urban emergency management as follow:

$$w_i = \frac{(\otimes_{j=1}^{n} g_{ij})^{1/n}}{\sum_{i=1}^{n} (\otimes_{j=1}^{n} g_{ij})^{1/n}}, \quad i = 1, 2, \cdots, n \tag{5}$$

Step 3: Calculate the fuzzy comprehensive risk value according to the above relative weight and the severity of loss of each risk factor in urban significant emergency by the following formula:

$$R = \sum_{i=1}^{n} (w_i \otimes R_i) / \sum_{i=1}^{n} w_i \tag{6}$$

where,

R_i = The severity of loss of the risk factor u_i.

Step 4: Calculate the similarity measure $S(R, G_j)$ between the fuzzy comprehensive risk value R and each pre-established risk grade G_j, where G_j is the jth risk grade in the pre-established risk grade set G ={$G1$ (EH),$G2$ (VH),$G3$ (FH),$G4$ (M),$G5$ (L) }.

Step 5: Determine the risk warning grade of the unexpected urban significant emergency.

By means of the similarity degree calculated, we can determine the risk warning grade of the uncertain urban significant emergency.

If $k = \text{argmax}_j \{S(R, G_j)/1 \le j \le 5\}$, then the unexpected urban emergency should belong to the given risk grade G_k.

Step 6: According to the estimated early warning grade, we can design the decision mechanism and adopt the corresponding emergency response or strategy to reduce the risk of urban emergency as displayed in the following Table 4.

ILLUSTRATIVE EXAMPLE

Recently, emergency managers and field experts usually tend to employ fuzzy values to evaluate the uncertain urban emergency with respect to various warning indexes. In this section, we give a numeric example to illustrate the application of the proposed fuzzy AHP and fuzzy early warning degree evaluation approach in uncertain urban significant emergency management.

Example 1: Now suppose the urban government tries to design the emergency decision mechanism and carry out some emergency rescue measures, it requires the emergency management monitor all the uncertain warning index information of possible urban emergency and evaluate the comprehensive risk value of urban emergency and estimate the warning degree. Assume the set of risk factors U = {u_1 (serious environment disruption and bad public health condition), u_2 (disloyal disaster report), u_3 (incomplete emergency facility), u_4 (severe traffic jam)} must be taken into account for this urban significant emergency. And the fuzzy preference degree is evaluated by experts. From the related emergency management experts, assume we know that the severities of loss of the above four risk factors of urban significant emergency are serious, medium, weak and critical, respectively.

Our main task is to determine the early warning grade of the urban significant emergency involved fuzzy linguistic value. That is to decide which risk grade, out of the five grades G_1, G_2, …, G_5, the unexpected urban emergency should belong to. In what follows we employ the fuzzy extended AHP method to calculate the relative weight of each risk factor and then compute the total risk value of urban significant emergency and then help the related urban emergency management department adopt the corresponding decision mechanism to decrease the comprehensive risk of urban emergency.

First, we regard Table 5 as the fuzzy preference matrix $\widetilde{D} = (\widetilde{r}_{ij})_{4\times4}$ of risk factors, where $\widetilde{r}_{ij}$ denotes the fuzzy preference degree of risk factor u_i over u_j.

By using the extended fuzzy AHP and formulae (1), (2), (5), we can compute the relative weight vector of risk factors in urban emergency by the formula

$$w_i = \frac{(\otimes_{j=1}^{4} g_{ij})^{1/4}}{\sum_{i=1}^{4} (\otimes_{j=1}^{4} g_{ij})^{1/4}}, \quad i = 1,2,\cdots,4$$

Thus, the relative weight vector of all the risk factors of urban significant emergency are obtained as:

W_1 = (0.2927, 0.416 and 0.5863)
W_2 = (0.1124, 0.1698 and 0.259)

Table 5: Pair-wise comparison fuzzy preference relation of risk factors in urban significant emergency

	u1	u2	u3	u4
u1	(1, 1, 1)	(2/3, 1, 3/2)	(5/2, 3, 7/2)	(7/2, 4, 9/2)
u2	(2/3, 1, 3/2)	(1,1,1)	(2/7, 1/3, 2/5)	(2/3, 1, 3/2)
u3	(2/7, 1/3, 2/5)	(5/2, 3, 7/2)	(1,1,1)	(5/2, 3, 7/2)
u4	(2/9, 1/4, 2/7)	(2/3,1,3/2)	(2/7,1/3,2/5)	(1,1,1)

W_3 = (0.2177, 0.2941 and 0.3956)
W_4 = (0.0854, 0.1201 and 0.1711).

Next, according to the given severity of loss of each risk factor in urban significant emergency, we know

(R_1, R_2, R_3, R_4)

= {Serious, Medium, Weak and Critical}

= (0.6, 0.7, 0.8), (0.4, 0.5, 0.6), (0.3, 0.4, 0.5), (0.9, 1, 1)}

From the previous formulae (5), (6), we calculate the fuzzy comprehensive risk value of urban emergency:

$$R = \sum_{i=1}^{4} w_i R_i \Big/ \sum_{i=1}^{4} w_i$$

= (0.1756, 0.2912, 0.469) + (0.045, 0.0849 and 0.1554) + (0.0653, 0.1176, 0.1978) + (0.0769, 0.1201, 0.1711)
= (0.3628, 0.6138, 0. 9933)

Then, according to the similarity formula (3) between fuzzy numbers, we compute the similarity measures between the calculated fuzzy risk value and each given risk grade in G = {G1 (EH), G2 (VH), G3 (FH), G4 (M), G5 (L)}.

$S(R, G_1)$ =0. 7418, $S(R, G_2)$ =0.8585,
$S(R, G_3)$ =0.9818, $S(R, G_4)$ =0.7988, $S(R, G_5)$ = 0. 6968

Since

$$S(R,G_3) > S(R,G_2) > S(R,G_4) > S(R,G_1) > S(R,G_5)$$

i.e., 3 = argmax$_j$ {$S(R, G_j)/G_j \in G$}, we know that the comprehensive risk of urban significant emergency should belong to G_3 grade and the risk of this urban significant emergency may be “Fairly high” and marked by “Yellow alarm”. That is to say, the unexpected urban significant emergency will undertake some risk of grade G_3. The related urban emergency management department should raise the corresponding warning and take emergency mechanism or strategy to monitor the safety hazard and estimate the public interest losses of intimidate, even coordinate all kinds of urgent management facilities among different municipal zones and districts to decrease the risk of the unexpected urban emergency before implementing some emergency response.

CONCLUSION

In this study, we propose an extended fuzzy AHP to calculate the relative weight of each uncertain risk factor, it is then used to compute the fuzzy comprehensive risk value of urban significant emergency. Finally, according to the similarity measure between the evaluated fuzzy comprehensive risk value and each given risk grade, we can assign the unknown urban significant emergency to a proper warning grade, which can facilitate the related urban emergency management department make the correct decision mechanism in accord with the early warning evaluation result.

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