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A New Early Warning Index Selection and Weight Assignment Method for Urban Significant Emergency in Uncertain Environment

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Abstract: In the complex real-life environment, many index values of urban emergency are easily expressed by fuzzy linguistic terms. In this study, we present a new weight assignment approach for the selected warning indexes of urban emergency by using extended fuzzy AHP and the urgent decision-making approach for uncertain urban emergency is then presented. By ranking of the aggregation values of all the warning indexes of urban emergency, we can order the severity of each urban emergency and select the most severe urban emergency. Finally, a numeric example is given to illustrate the application of the presented fuzzy warning index weighting method to the urgent decision-making for uncertain urban emergency involving fuzzy evaluation value.

Keywords: Aggregation operator, fuzzy AHP, urban emergency, warning index, weight

INTRODUCTION

With the great development and expansion of city, the frequency and risk of significant emergencies are increasing in numerous large and medium-sized cities. Urban emergency index analysis and early warning decision-making become very important issues in emergency management research. As is well known, many uncertain indexes usually incur the urban emergency. Simultaneously, the significant urban emergency inevitably affects many urban aspects, including urban economy damage, safety of urban environment and citizen casualties. Recently, the method of index selection and weight evaluation for emergency early warning was proposed by Zhang (2008). Many authors (He and Lu, 2010; Zhao, 2009; Zhou and Zhang, 2006) have proposed some emergency decision-making methods for urban emergency. Some early warning management approaches for urban emergencies have also been presented (He and Li, 2012; Ye, 2007; Lang, 2011; Wang, 2005; Ma *et al*., 2006). The emergency response mechanism and management strategy have been investigated in literature (Sun, 2007; Tang, 2008; Yang and Ding, 2009; Gao, 2010; Wen and Bian, 2006; Chen and Chen, 2007b). However, most of the existing early warning index analysis method and emergency decision models can only deal with the urban emergency with precise index value and weight of emergency index.

In fact, due to the increasing complexity of the real-life environment and the lack of knowledge about the problem domain, most of the real-world problems, like urban emergency index selection and emergency decision, are involved variety of uncertainty, like fuzzy number (Deng *et al*., 2004) or fuzzy linguistic term (Rodriguez *et al*., 2012). Especially, in the evaluation process of urban significant emergency it will inevitably involve some uncertain indexes like the severe economic loss, the heavy casualties, the unauthentic emergency report and the serious traffic jam, as well as the low emergency response of urban government. Also, the values of above warning indexes are easily assessed by fuzzy linguistic terms.

Although some researchers studied the approaches of fuzzy index analysis, few works focus on investigating the fuzzy warning index analysis of urban emergency. For example, some authors (Chen, 2003; Chen, 2007a) studied the fuzzy decision risk analysis method based on the ranking of generalized fuzzy numbers. Fuzzy AHP was also employed in supplier selection and service quality evaluation (Kahraman *et al*., 2003; Buyukozkan and Cifci, 2012). However, the fuzzy warning index selection and weight assignment methods were not solved effectively. In fact, most of the existing fuzzy index analysis methods have some drawbacks, which cannot effectively determine the rational weights of fuzzy warning indexes for urban emergency. And we notice that different weight assignment for early warning index influences the emergency decision result. So, in this study we try to propose an effective approach for early warning index selection and weight assignment of uncertain urban emergency and then deal with the urban emergency decision problem involved fuzzy evaluation value in uncertain environment.

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PRELIMINARIES

Fuzzy Set (FS) is a useful generalization of the ordinary set, which has been proved to be more suitable way for dealing with vagueness and uncertainty. Particularly, the similarity measure and distance measure of FSs play very important roles in the application fields like pattern recognition, risk analysis and decision-making.

Definition 1: A fuzzy set $\tilde{a}$, $\tilde{a} = (l_a, m_a, u_a)$ in a universe of discourse X in R is called a triangular fuzzy number if its membership function $\tilde{f}_a$ can be expressed as the following form.

$$f_{\tilde{a}}(x) = \begin{cases} 0, & x \le l_a, or \quad x > u_a; \\ \dfrac{x - l_a}{m_a - l_a}, & l_a < x \le m_a; \\ \dfrac{u_a - x}{u_a - m_a}, & m_a < x \le u_a. \end{cases}$$

Definition 2: Let $\tilde{a} = (l_b, m_b, u_b)$, $\tilde{b} = (l_b, m_b, u_b)$, be two triangular fuzzy numbers, the addition and multiplication operations between them are given as:

$$\tilde{a} + \tilde{b} = (l_a + l_b, m_a + m_b, u_a + u_b) \tag{1}$$
$$\tilde{a} \times \tilde{b} = (l_a, m_a, u_a) \times (l_b, m_b, u_b) = (l, m, u)$$

where, $l = \min(l_a l_b, l_a u_b, u_a l_b, u_a u_b)$, $m = m_a m_b$, $u = \max(l_a l_b, l_a u_b, u_a l_b, u_a u_b)$

Remark 1: If $l_a, m_a, u_a, l_b, m_b, u_b > 0$, $w > 0$, then $\tilde{a} \times \tilde{b} = (l_a, m_a, u_a) \times (l_b, m_b, u_b) = (l_a l_b, m_a m_b, u_a u_b)$ $\tilde{a} / \tilde{b} = (l_a, m_a, u_a) / (l_b, m_b, u_b) = (l_a / u_b, m_a / m_b, u_a / l_b)$ and $w\tilde{a} = (wl_a, wm_a, wu_a)$.

Definition 3: Let C = $\{c_1, c_2, .., c_n\}$be the warning index set and $(g_{ij})_{n\times n}$ be the pair-wise comparison fuzzy preference matrix, where g_{ij} represents the fuzzy preference degree of index c_i over index c_j, $g_{ji} = 1/g_{ij}$, the weight of each warning index of urban emergency is defined by:

$$w_i = \frac{(\prod_{j=1}^{n} g_{ij})^{1/n}}{\sum_{i=1}^{n} (\prod_{j=1}^{n} g_{ij})^{1/n}} \tag{2}$$

Definition 4: The centroid method is very useful to deal with defuzzification problems and fuzzy ranking problem. The formula for simply calculating the centroid $(x_{\tilde{a}}, y_{\tilde{a}})$ of fuzzy number $\tilde{a} = (l_a, m_a, u_a)$ is defined as follows:

$$x_{\tilde{a}} = \frac{(l_a + m_a + u_a)}{3} \tag{3}$$
$$y_{\tilde{a}} = =1/3$$

Definition 5: The ranking value of fuzzy number $\tilde{a} = (l_a, m_a, u_a)$ is defined as:

$$Rank(\tilde{a}) = \sqrt{x_{\tilde{a}}^2 + y_{\tilde{a}}^2} \tag{4}$$

The larger the value of Rank $(\tilde{a})$, the better the ranking of fuzzy number $\tilde{a} = (l_a, m_a, u_a)$.

NEW METHOD FOR WARNING INDEX SELECTION AND WEIGHT ASSIGNMENT FOR URBAN EMERGENCY

As we know, many types of indexes probably incur urban significant emergency. Especially in the uncertain emergency decision environment, the accurate value of early warning index is difficult to measure. But, it can be easily estimated by fuzzy linguistic term in the real-life world. So, we can conveniently compare the preference degree between two warning indexes and get the fuzzy preference relation on early warning index set. Through the extended fuzzy AHP analysis method, we can weight all the early warning indexes of urban significant emergency.

Generally, by emergency management expert questionnaire survey and statistical analysis from urban emergency management we can easily get some important indexes which possibly cause the urban significant emergency. Also, through emergency supervisors and search engines, we can obtain much information of urban emergency warning indexes including subjective and objective indexes. For the sake of dealing with early warning and emergency decision making, we firstly choose the finite comprehensive and hierarchical indexes from all the possible alternate indexes based on the well-established principle that each index should possess independency, sensitivity and representation, as well as guidance quality. Therefore, we need to employ many emergency management decision experts to assign scores to all the alternate emergency indexes, then to select the relative important early warning index with higher scores. Generally, after index early warning analysis and selection, there are still multi-level warning indexes that should be taken into account. Usually, every urban significant emergency comprises the following first-grade indexes, like urban emergency power index (c_1), network media influence index (c_2) and government emergency coping capacity(c_3).

Table 1: Linguistic terms for evaluating urban emergency with respect to fuzzy warning index

Linguistic terms	Fuzzy numbers
Extremely strong (ES) /Extremely high (EH) / Extremely big (EB)	(1 , 1, 1)
Very very strong (VVS) /Very very high (VVH) /Very very big (VVB)	(0.9, 0.95, 1)
Very strong (VS) /Very high (VH) /Very big (VB)	(0.8, 0.9, 0.95)
Strong (S) /High (H) /Big (B)	(0.58, 0.7, 0.8)
Medium (M)	(0.4, 0.5, 0.6)
Weak (W) /Low (L)/Tiny (T)	(0.2, 0.3, 0.42)
Very weak (VW) / Very low (VL) /Very tiny (VT)	(0.15, 0.2, 0.25)
Very very weak (VVW)/Very very low (VVL) /Very very tiny (VVT)	(0, 0.05, 0.1)
Extremely weak (EW) / Extremely low (EL) / Extremely tiny (ET)	(0, 0, 0)

Additionally, each first-grade early warning index also has many second-grade warning indexes. In general, urban emergency power index (c_1) briefly consists of the following second-grade indexes including time duration, extent of diffusion, environment disruption degree, traffic jam degree, severity of economic loss and property damage. And Network media influence index (c_2) briefly consists of the following second-grade indexes including sentiment attention degree, spreading degree of network media sentiment, emotion tendency, behavior tendency, authentic urban of network media report. The government emergency coping capacity (c_3) briefly consists of the following second-grade indexes, including response speed, information transparency, emergency evacuation capacity, urban emergency resource allocation capacity, urban government responsibility, people-centralized degree.

Notably, in uncertain decision environment the above-mentioned urban emergency early warning indexes are difficult to measure by precise real numbers, instead, they are easily assessed by emergency managers and related field experts in terms of fuzzy words, like strong emergency power index, serious economic loss, severe environment disruption, wicked emergency report, low response speed, weak emergency evacuation capacity, incomplete emergency rescue facility and so on.

Moreover, the evaluation value of every alternate urban significant emergency with respect to each of the early warning indexes are easily expressed by the fuzzy linguistic terms like extremely strong, very strong, strong, medium, weak, very weak, extremely weak rather than by accurate real numbers.

In order to simplify the assessing each early warning index of urban significant emergency, a unified set of linguistic variables is predetermined in Table 1, which can be adapted to every warning index from the satisfaction perspective.

Based on the above analysis and the previous formulae, next we try to develop an extended fuzzy AHP method to determine the weight of warning index and then to make emergency decision for the urban significant emergency involved fuzzy linguistic values in uncertain environment.

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

Intensity of importance	Definition of grade	Fuzzy number
9	Extremely strong importance	(7, 9, 9)
7	Very strong importance	(5, 7, 9)
5	Strong importance	(3, 5, 7)
3	Moderate importance	(1, 3, 5)
2	Fair importance	(1, 2, 3)
1	Equal importance	(1, 1, 3)

Step 1: By statistical questionnaire and the scores assigned by emergency management experts, we first construct all the fuzzy preference relations over first-grade and the second-grade early warning index level of emergency by comparing importance degree between warning indexes as the following Table 2.

Then, by the extended fuzzy AHP and formula (2), we can first compute the weight vector of each warning index level. Moreover, by using multiplication of the weights of all the warning indexes of top-level and its sub-level, we can finally obtain the overall weight of each warning index regarding the urban significant emergency decision goal. If the weight of some index is very small, then this warning index can be omitted. We should select the early warning indexes with weights at least 0.1.

Step 2: By using the above-assessed weight of each warning index, we compute the fuzzy weighted arithmetic aggregation value $\tilde{e}_{\mathrm{i}}$ of each urban emergency e_i by applying formula (1).

Step 3: Compute the simple centroid $(x_{\tilde{a}}, y_{\tilde{a}})$ of each fuzzy number $\tilde{e}_{\mathrm{i}}$ by using formula (3).

Step 4: By using formula (4) we can calculate the ranking value Rank $(\tilde{e}_{\mathrm{i}})$ of each fuzzy number $\tilde{e}_{\mathrm{i}}$ and then we rank all the severities of the potential urban significant emergencies.

If Rank($\tilde{e}_{\mathrm{i}}$)> Rank($\tilde{e}_{\mathrm{i}}$), then the alternate urban emergency e_i is more severe than e_k, then we must deal with emergency e_i earlier than e_k.

By the above emergency decision approach, the urban emergency management can cope with the emergency more efficiently according to the severity ranking of all the possible urban emergencies. From the selected early warning indexes and the severity ranking result of all the alternate urban emergencies, we can also design the decision mechanism and adopt the corresponding emergency response or decision strategy

Table 3: Pair-wise comparison of all the warning indexes of urban significant emergency

	C1	C2	C3		
C1	(1, 1, 3)	(3, 5, 7)	(5, 7, 9)		
C2	(1/7, 1/5, 1/3)	(1, 1, 3)	(1/5, 1/3, 1)		
C3	(1/9, 1/7, 1/5)	(1, 3, 5)	(1, 1, 3)		
	C11	C12	C13		
C11	(1, 1, 3)	(5, 7, 9)	(1, 3, 5)		
C12	(1/9, 1/7, 1/5)	(1, 1, 3)	(3, 5, 7)		
C13	(1/5, 1/3, 1)	(1/7, 1/5, 1/3)	(1, 1, 3)		
	C21	C22	C31	C32	C33
C21	(1, 1, 3)	(5, 7, 9)			
C22	(1/9, 1/7, 1/5)	(1, 1, 3)			
C31			(1, 1, 3)	(5, 7, 9)	(1, 3, 5)
C32			(1/9, 1/7, 1/5)	(1, 1, 3)	(1/7, 1/5, 1/3)
C33			(1/5, 1/3, 1)	(3, 5, 7)	(1, 1, 3)

Table 4: Emergency decision information system with uncertain fuzzy linguistic terms

Emergency Index	e_1	e_2	e_3	e_4
C11	VT	EB	VB	T
C12	B	VB	T	B
C13	V S	VW	M	V S
C21	V VH	H	VH	V VH
C22	H	V VL	V VH	H
C31	M	S	W	V VW
C32	T	VT	B	VB
C33	S	VW	M	W

to avoid or decrease the possible losses of urban significant emergency.

ILLUSTRATIVE EXAMPLE

In uncertain setting, the urban emergency management experts usually use the linguistic value to evaluate the importance of the index and to rate the alternatives with respect to various warning indexes. Most of the existing emergency decision problems have only precise values for the performance ratings and for the index weights. Therefore, in order to select the most severe one from a number of alternate urban emergences with different uncertain indexes, we will extend the fuzzy AHP to determine the priority of different early warning indexes and then choose the most severe urban emergency for urban significant emergency management. The emergency early warning and decision evaluation procedure mainly consists of two steps as follows:

- After constructing the warning evaluation index hierarchy, calculate the fuzzy weights of warning indexes by applying the fuzzy comparison matrix and the improved fuzzy AHP method mentioned above.
- Comparing the ranking values of all the alternate urban emergencies, achieve the final severity ranking results. The detailed urban emergency early warning index weight assignment and decision are illustrated in the following.

Example 1: Suppose the urban emergency management departments acquire much information of uncertain early warning indexes of some possible urban emergencies by employing some supervisor control platforms or search engines and they need to estimate the severity of all the possible urban emergencies, then make final emergency decision making. Now assume there exist multiple alternate urban significant emergencies $E = \{e_1, e_2, e_3, e_4\}$, which may be influenced by many uncertain early warning indexes. By the aid of statistical questionnaire from many emergency decision experts and through well-established principle of early warning index selection, here we choose two first-grade warning indexes including urban emergency power index (c_1), network media influence index (c_2), government emergency coping capacity (c_3). Moreover, in first-grade warning index level c_1 we select the following second-grade indexes: environment disruption degree (c_{11}), traffic jam degree (c_{12}), severity of economic loss (c_{13}). In warning index (c_2) level we simply choose the following second-grade indexes, sentiment attention degree (c_{21}), spreading degree of network media sentiment (c_{22}). And in warning index level c_3 we also select the following second-grade indexes: response speed (c_{31}), emergency resource allocation capacity(c_{32}), information transparency (c_{33}).

Moreover, by emergency experts assigning fuzzy importance degree to each pair of warning indexes, we can easily get the fuzzy preference comparison matrix over each level of indexes as shown in Table 3. Also, the evaluated values of all the potential urban emergencies with respect to the uncertain warning indexes are given by related expertise as shown in the following Table 4. Our main task is to determine the severity ranking of all the possible urban emergencies involved fuzzy numbers. Ultimately, we make final urgent decision to select the most severe one we must deal with first of all, out of all the potential urban emergencies.

In what follows we employ the extended fuzzy AHP method to assign the rational weight of each early warning index of urban significant emergency and then facilitate the related emergency management department adopting the corresponding decision strategy to decrease the risk loss of urban emergency.

Table 5: The priority weights in the warning index levels of urban emergency by the extended fuzzy AHP

C 1	(0.3015, 0.7383, 1.7644)		
C 11		(0.2208, 0.6798, 1.8936)	(0.0666, 0.5019, 3.3411)
C 12		(0.0895, 0.2203, 0.5955)	(0.027, 0.1626, 1.0507)
C 13		(0.0395, 0.0999, 0.3691)	(0.0119, 0.0738, 0.6512)
C 2	(0.0374, 0.0915, 0.3074)		
C 21		(0.1784, 0.75, 2.6762)	(0.0067, 0.0686, 0.8227)
C 22		(0.0798, 0.25, 1.1969)	(0.003, 0.0229, 0.3679)
C 3	(0.0588, 0.1702, 0.4434)		
C 31		(0.2018, 0.6491, 1.829)	(0.0119, 0.1105, 0.811)
C 32		(0.0297, 0.0719, 0.2085)	(0.0017, 0.0122, 0.0924)
C 33		(0.0995，0.279，0.9837)	(0.0059，0.0475，0.4362)

First, from the pair-wise fuzzy preference comparison relation Table 3 of the warning indexes, with respect to the urban emergency decision goal, by using formula (2) and taking Step 1 stated in Section 3 we can compute the weight vector and priority of each early warning index level as listed in Table 5.

Since the weight of sub-index 32 in Table 5, w_{32} = (0.0017, 0.0122, 0.0924), is very small, it can be ignored. And we only need to select the seven warning sub-indexes {c_{11}, c_{12}, c_{13}, c_{21}, c_{22}, c_{31}, c_{33}, which are viewed as seven criteria of the city significant emergency.

Thus, from linguistic term Table 1 we translate Table 5 regarding the selected seven warning sub-indexes into the following fuzzy decision matrix:

$$D = (\tilde{r}_{ji})_{7\times 4} =$$

$$D = (\tilde{r}_{ji})_{7\times 4:} \begin{pmatrix} (0.15,0.2,0.25) & (1.0,1.0,1.0) & (0.8,0.9,0.95) & (0.2,0.3,0.42) \\ (0.58,0.7,0.8) & (0.8,0.9,0.95) & (0.2,0.3,0.42) & (0.58,0.7,0.8) \\ (0.8,0.9,0.95) & (0.15,0.2,0.25) & (0.4,0.5,0.6) & (0.8,0.9,0.95) \\ (0.9,0.95,1) & (0.58,0.7,0.8) & (0.8,0.9,0.95) & (0.9,0.95,1.0) \\ (0.58,0.7,0.8) & (0,0.05,0.1) & (0.9,0.95,1) & (0.58,0.7,0.8) \\ (0.4,0.5,0.6) & (0.58,0.7,0.8) & (0.2,0.3,0.42) & (0,0.05,0.1) \\ (0.58,0.7,0.8) & (0.15,0.2,0.25) & (0.4,0.5,0.6) & (0.2,0.3,0.42) \end{pmatrix},$$

where, $\tilde{r}_{ij}$ is the fuzzy membership degree of urban emergency e_i with respect to j-th criteria considered. All the selected sub-indexes are regarded as the urban emergency decision criteria.

From the obtained fuzzy weight vector W of the selected sub-indexes in last column of Table 5 and by formula (1) we calculate fuzzy weighted arithmetic aggregation value $\tilde{e}_i$ of each urban emergency e_i with all fuzzy warning indexes below.

$$\tilde{e}_1 = \sum_{j=1}^{7} w_j \tilde{r}_{j1} = (0.0511, 0.4503 \text{ and } 4.2471)$$

$$\tilde{e}_2 = \sum_{j=1}^{7} w_j \tilde{r}_{j2} = (0.1017, 0.799 \text{ and } 5.9549)$$

$$\tilde{e}_3 = \sum_{j=1}^{7} w_j \tilde{r}_{j3} = (0.0762, 0.6778 \text{ and } 5.7579)$$

$$\tilde{e}_4 = \sum_{j=1}^{7} w_j \tilde{r}_{j4} = (0.0475, 0.4318 \text{ and } 4.2438)$$

According to formula (3) we can compute the corresponding simple centroid $(x_{\tilde{e}_i}, y_{\tilde{e}_i})$ of each fuzzy number $\tilde{e}_i$ regarding the urban emergency e_i.

$(x_{\tilde{e}_1}, y_{\tilde{e}_1})$ = (1.5828, 0.333), $(x_{\tilde{e}_2}, y_{\tilde{e}_2})$ = (2.2852, 1/3), $(x_{\tilde{e}_3}, y_{\tilde{e}_3})$ = (2.1706, 0.333), $(x_{\tilde{e}_4}, y_{\tilde{e}_4})$ = (1.5744, 0.333).

By using formula (4) we can calculate the ranking value Rank($\tilde{e}_i$) of each fuzzy number $\tilde{e}_i$, Rank($\tilde{e}_i$) = 1.6175, Rank $\tilde{e}_2$ = 2.3094; Rank $\tilde{e}_3$ = 2.196; Rank $\tilde{e}_4$ =1.6093.

Since Rank ($\tilde{e}_2$)> Rank ($\tilde{e}_3$) > Rank ($\tilde{e}_1$)> Rank ($\tilde{e}_4$), we can rank the severity of each possible urban significant emergency as $e_4 \prec e_1 \prec e_3 \prec e_2$.

Thus, the urban emergency e_3 is the optimal decision alternative. That is to say, e_2 is the most severe urban emergency in all the possible urban emergencies, the urban emergency management decision-maker must firstly deal with this urban emergency, next to cope with the secondary severe emergency e_3, then e_1 and e_4. The related urban emergency management will raise the corresponding early warning and take urgent decision mechanism to coordinate all kinds of emergency facilities among different municipal zones and districts to avoid or decrease the risk loss of the unexpected urban significant emergency before implementing some emergency response.

CONCLUSION

In this study, we employ an extended fuzzy AHP method to assign the rational weights of early warning indexes for urban significant emergency. And then by using fuzzy weighted aggregation operator of all the warning index value we can rank all the severities of urban emergencies and make emergency decision to

select the most severe urban emergency, which helps the related urban emergency management department take the corresponding emergency strategy and mechanism in accord with the obtained severity ranking result of the urban emergency.

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