A Hesitant Fuzzy Linguistic Model for Emergency Decision Making based on Fuzzy TODIM method

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Abstract—**The importance of emergency decision making (EDM) has grown up in recent years because of the frequent occurrence of multiple emergency events (EEs) that have caused important social and economic losses. EDM plays a relevant role when it is necessary to mitigate property and lives losses and reducing the negative impacts on the social and environmental development. Real-world EDM problems are usually characterized by complexity, hard time constraints, lack of information and the impact of the psychological behaviors which makes it very challenging task for the decision maker. This characterization shows the need of dealing with different types of uncertainty and the managing of behaviors to face these problems. This contribution proposes a new emergency decision model that first, uses fuzzy linguistic information to model the subjective information elicited by the decision maker under uncertainty and also the modelling of his/her hesitancy for assessing his/her judgements by using hesitant fuzzy linguistic term sets. Second it integrates the decision maker's psychological behavior by using the prospect theory in a fuzzy based environment. Finally, an example of application of the decision model is carried out to show its validity and applicability.**

I. INTRODUCTION

The frequent occurrence of emergency events (EEs) nowadays such as terrorist attacks, earthquakes, flooding and other natural disasters that are quite sensitive to the society has made that Emergency Decision Making (EDM) drawn increasing attention from both government and academia, because of its prominent role in order to reduce and relieve losses and impacts caused by such EEs. It covers very broad and diverse activities resulting on a high complex and ill-structured decision process, because it may involve different and specific difficulties coming from different sources such as inadequate and incomplete information about the EEs, especially in the early stage of occurrence [1], [2]. In such a type of situation the decision maker (DM) is usually bounded cognition [3] and under pressure not only because of the urgent time constraints of EDM, but also because his/her decision might provoke serious consequences [4], hence, it is common that the DM might hesitate about his/her judgments regarding the EE.

EDM solving processes can be summarized in the following phases: 1) After the EE happened a decision framework is defined in order to structure the decision problem and the information about the EE, 2) During the gathering process, the judgements and assessments elicited by DM related to the EE are collected; 3) From the information gathered, it is applied a selection process, in which different multi-criteria decision making (MCDM) methods [5] can be applied to obtain an evaluation of the alternatives for the EDM problem that will be used to cope with the EE [1], [4], [6], etc. This general scheme of an EDM is shown in Fig. 1.

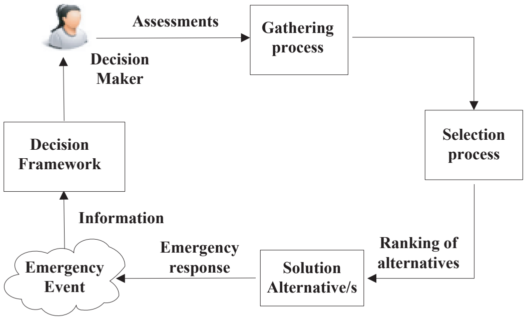

Fig. 1. General scheme of EDM

Even though classical decision theory provides probabilistic tools and models to cope with uncertainty in EDM, often there are aspects of these uncertainties that do not have a probabilistic character. In such situations the use of linguistic descriptors [7], to elicit knowledge and preferences about the alternatives/criteria, has produced successful results [8] but sometimes the use of simple linguistic terms are somehow not enough to model in EDM the DM's uncertain knowledge about the criteria and alternatives [9]. Hence, the use of linguistic expressions based on hesitant fuzzy linguistic term sets (HFLTS)[10] can improve the modelling not only of the subjective judgements elicitation by the DM but also his/her hesitation about such judgments and knowledge because the information about the EE is inadequate or incomplete.

Additionally, different behavioral experiments [3], [11], [12] have shown that human beings are usually bounded cognition in decision making processes under risk and uncertainty, and their psychological behaviors are crucial in such processes.

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Therefore, DM's psychological behaviors should be considered in the EDM process. Such an important issue has been addressed in current EDM approaches [1], [6], however, they are not able to deal with DM's psychological behaviors under a fuzzy linguistic environment.

As far as we know until now there is no any proposal in current EDM approaches that considers DM's hesitancy from a qualitative point of view and much less together the DM's psychological behavior. Therefore, this contribution aims at developing a new fuzzy decision model for EDM that would be able to deal with linguistic information including complex linguistic expressions based on HFLTS to model DM's hesitation in the elicitation process during the gathering phase and at the same time consider DM's psychological behaviors by using fuzzy TODIM method [13], [14] based on prospect theory [11].

The remaining of this contribution is organized as below: Section II briefly introduces different concepts and methods that will be utilized in this contribution. Section III presents a new EDM method that considers the DM's hesitancy and their psychological behaviors. In Section IV, a case study is provided. The conclusions and future works are pointed out in Section V.

II. PRELIMINARIES

This section provides a brief introduction about the fuzzy linguistic information including HFLTS and the fuzzy TODIM method that are utilized in this contribution.

A. Fuzzy Linguistic Information and Hesitant Fuzzy Linguistic Term Sets

A fairly common approach to model qualitative linguistic information is the fuzzy linguistic approach [7] based on the fuzzy set theory. It uses the concept of linguistic variable as *"a variable whose values are not numbers, but words or sentences in a natural or artificial language"* [7]. A value expressed linguistically is less precise than a number, but it is closer to human beings solving process when dealing with uncertainty.

The use of linguistic variables makes necessary the selection of adequate linguistic descriptors for the term set, their syntax and semantics. The selection of the syntax and suitable semantics is crucial to determine the validity of the fuzzy linguistic approach, and exist different approaches to choose the linguistic descriptors and different ways to define their linguistic semantics [7], [8]. The semantics of the terms is represented by fuzzy numbers, described by membership functions. Some authors consider that parametric membership functions (trapezoidal, triangular) are good enough to capture the vagueness of these linguistic assessments [15]. The trapezoidal representation is achieved by the 4-tuple (a, b, d, c), in which b and d indicate the interval in which the membership value is 1, with a and c indicating the left and right limits of the definition domain of the trapezoidal membership function. A particular case of this type of representation are the linguistic assessments whose membership functions are triangular, i.e., $b = d$. Figure 3 shows an example of a linguistic term set with the syntax and semantics defined.

The use of either simple terms or labels can hardly express in many complex decision situations the DM's knowledge in a proper and adequate way mainly when DMs hesitate among different linguistic values, especially in decision situations under pressure or when the available information regarding the decision problem is vague and incomplete. To cope with such situations, the idea of HFLTS [10] proposed by Rodríguez et al. enables DMs to reflect their hesitancy in qualitative contexts when they provide their assessments.

Definition 1 [10] *Let $S = \{s_0, s_1, \dots, s_g\}$ be a linguistic term set, a HFLTS, H_S, on S is an ordered finite subset:*

$$H_S = \{s_i, s_{i+1}, \dots, s_j\}, s_t \in S, t \in \{i, i+1, \dots, j\} \tag{1}$$

Example 1 *Let S=\{very poor,poor,medium,good,very good\}, according to Definition 1, two HFLTSs on S can be expressed as follows:*

H_S^1=\{very poor,poor\}

H_S^2=\{good,very good\}

Nevertheless, in real world problems, DMs do not elicit their judgments/assessments by utilizing the multiple linguistic terms, but by using linguistic expressions. Therefore, a context-free grammar, G_H, was proposed in [16] to generate complex linguistic expressions approach to the natural language utilized by the DMs in such hesitant situations. This approach has drawn great attention and has been diffusely applied to solve different problems [14], [17], [18], [19] due to its powerfulness and usefulness.

Definition 2 [10] *Let $S = \{s_0, s_1, \dots, s_g\}$ be a linguistic term set and G_H be a context-free grammar. The elements of $G_H = (V_N, V_T, I, P)$ are defined as below:*

V_N =\{ ⟨primary term⟩ ,⟨composite term⟩,⟨unary relation⟩ ,⟨binary relation⟩,⟨conjunction⟩\}

V_T = \{lower than, greater than, at least, at most, between, and, $s_0, s_1, \dots, s_g$\}

$I \in V_N$

P = \{I:: = ⟨primary term⟩|⟨composite term⟩
⟨composite term⟩ :: = ⟨unary relation⟩ ⟨primary term⟩|⟨binary relation⟩
⟨primary term⟩ ⟨conjunction⟩ ⟨primary term⟩
⟨primary term⟩ :: = s_0 $|s_1| \dots |s_g$
⟨unary relation⟩ :: = lower than |greater than |at least |at most
⟨binary relation⟩ :: = between
⟨conjunction⟩ :: = and\}

The expressions generated by G_H may be either single linguistic label $s_t \in S$, or complex linguistic expressions denoted as S_{ll} (see [16] for further details).

Example 2 *Let S =\{very poor,poor,medium,good,very good\}. Three possible complex linguistic expressions S_{ll_1}, S_{ll_2}, S_{ll_3} generated by G_H, could be the following ones:*

S_{ll_1} = between very poor and poor
S_{ll_2} = at least good
S_{ll_3} = at most medium

To carry out computations with complex linguistic expressions they are represented by a fuzzy number [18]. To do so, S_{ll} are first transformed into H_S by utilizing the transformation function E_{G_H}.

Definition 3 [16] *Let E_{G_H} be a transformation function that transforms S_{ll} into H_S.*

$$E_{G_H} : S_{ll} \rightarrow H_S \tag{2}$$

Once the expressions are represented by multiple linguistic labels, their fuzzy envelop is obtained [18].

Definition 4 [18] *Let $env_F(\cdot)$ be a fuzzy envelop function that transforms H_S into its fuzzy membership function.*

$$env_F(H_S) = \Gamma(x, y, z, w) \tag{3}$$

$\Gamma(x, y, z, w)$ being a trapezoidal fuzzy membership function (see [18] for further details).

B. Fuzzy TODIM method

TODIM (an acronym in Portuguese "TOmada de Decisão Iterativa Multicritério") method is a popular MCDM method based on prospect theory [11] to capture DM's psychological behavior.

Due to the fact that this contribution deals with fuzzy information including DM's hesitation, and the assessments provided by DM are represented by trapezoidal fuzzy membership functions, a fuzzy TODIM method will be utilized due to its advantage of capturing the DM's psychological behaviors under fuzzy environment. It is briefly summarized below [20].

Let $A = \{a_1, a_2, \ldots, a_m\}$ be a set of alternatives, a_i denotes the *i-th* alternative, $i = 1, 2, \ldots, m$. $C = \{c_1, c_2, \ldots, c_n\}$ be a set of criteria/attributes, $w_c = (w_{c_1}, w_{c_2}, \ldots, w_{c_n})$ be the weighting vector of criteria/attributes, w_{c_j} denotes the weight of *j-th* criterion/attribute, c_j, $j = 1, 2, \ldots, n$. Let $P = (p_{ij})_{m\times n}$ be a fuzzy decision matrix, $p_{ij} = (p^1_{ij}, p^2_{ij}, p^3_{ij}, p^4_{ij})$ denotes the rating of alternative a_i concerning c_j.

Step 1: The fuzzy decision matrix, $P = (p_{ij})_{m\times n}$, is normalized into $\bar{P} = (\bar{p}_{ij})_{m\times n}$, according to the cost and benefit criteria.

Step 2: The reference criterion c_r is determined and the relative weight w_{jr} of c_j can be obtained, i.e.,

$$w_{jr} = \frac{w_{c_j}}{w_r} \tag{4}$$

where $w_r = max\{w_{c_j} | j = 1, 2, \ldots, n\}$.

Step 3: The dominance degree, $\Phi_j(a_i, a_k)$, of a_i over the rest of alternatives $a_k (k = 1, 2, \ldots, m)$ regarding c_j is calculated, i.e.,

$$\Phi_j(a_i, a_k) = \begin{cases} \sqrt{w_{jr}/(\sum_{j=1}^{n} w_{jr})} d(\bar{p}_{ij}, \bar{p}_{kj}), \\ F(\bar{p}_{ij}) - F(\bar{p}_{kj}) \geq 0 \\ \\ -\frac{1}{\theta}\sqrt{(\sum_{j=1}^{n} w_{jr})/w_{jr}} d(\bar{p}_{ij}, \bar{p}_{kj}), \\ F(\bar{p}_{ij}) - F(\bar{p}_{kj}) < 0 \end{cases} \tag{5}$$

where $d(\bar{p}_{ij}, \bar{p}_{kj})$ represents the distance between two fuzzy numbers $\bar{p}_{ij}$ and $\bar{p}_{kj}$. θ denotes the attenuation factor of the losses, $\theta > 0$. $F(*)$ is a defuzzification function [20].

Step 4: The dominance degree, $\delta(a_i, a_k)$, of alternative a_i over the rest of alternatives a_k is calculated, i.e.,

$$\delta(a_i, a_k) = \sum_{j=1}^{n} \Phi_j(a_i, a_k) \tag{6}$$

Step 5: The overall dominance degree, $\eta(a_i)$, of alternative a_i is calculated, i.e.,

$$\eta(a_i) = \frac{\sum_{k=1}^{m} \delta(a_i, a_k) - \min_i\{\sum_{k=1}^{m} \delta(a_i, a_k)\}}{\max_i\{\sum_{k=1}^{m} \delta(a_i, a_k)\} - \min_i\{\sum_{k=1}^{m} \delta(a_i, a_k)\}} \tag{7}$$

Step 6: According to the overall dominance degree of each alternative, the corresponding ranking can be determined. The bigger $\eta(a_i)$, the better alternative a_i.

III. A HESITANT FUZZY LINGUISTIC MODEL FOR EMERGENCY DECISION MAKING

This section introduces a new EDM model that is able to deal with linguistic information including HFLTS and DM's psychological behaviors by using the prospect theory. This new EDM model extends the general scheme introduced in Fig. 1 by adding a new phase, so-called *"Unification process"* and modifying the selection process by using a MCDM based on the prospect theory. Therefore the new model will consist of the following phases (see Fig. 2):

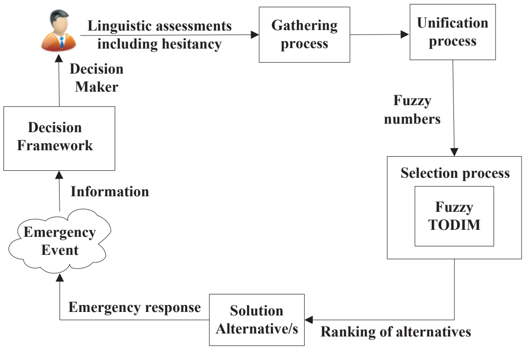

Fig. 2. Linguistic EDM method based on fuzzy TODIM coping with HFLTS

1) *Decision framework*: The linguistic structure of the EDM problem is defined.
2) *Gathering process*: Linguistic assessments and expressions provided by DM are gathered.
3) *Unification process*: Linguistic expressions and linguistic assessments provided by DM are conducted into a fuzzy representation to apply a fuzzy MCDM method.
4) *Selection process-fuzzy TODIM method*: Due to the fact that this proposal takes into account DM's psychological behaviors, the MCDM method applied will be the Fuzzy TODIM method based on prospect theory [11].

These phases are further described in the coming subsections.

A. Decision Framework

A common framework for EDM consists of a decision matrix, $X = (x_{ij})_{m\times n}$, in which, x_{ij} $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$, denotes the assessments/judgements over the emergency alternatives, a_i, concerning each criterion, c_j.

$$X = \begin{array}{c} \\ a_1 \\ a_2 \\ \vdots \\ a_m \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array}$$

B. Gathering Process

According to the information obtained by the DM in the early stage of the EE, he/she will provide his/her assessments for the decision matrix, $X = (x_{ij})_{m\times n}$, where either $x_{ij} \in S$, or $x_{ij} \in S_{ll}$, if the DM hesitates about his/her knowledge.

C. Unification process

Due to the fact that the information provided by the DM can be linguistic terms or linguistic expressions, both of them should be conducted into a common expression domain to facilitate further computations with such an input information. For sake of simplicity, our proposal keeps the parametric membership function for linguistic terms and will transform linguistic expressions into a fuzzy trapezoidal membership function representation by a two-step process:

1) First, the linguistic expressions, $x_{ij} \in S_{ll}$, are transformed into HFLTS, H_S, by using the transformation function, E_{G_H}, revised in Definition 3.

$$E_{G_H}(X(x_{ij})_{m\times n}) \to \tilde{X}(\tilde{x}_{ij})_{m\times n} \tag{8}$$

$\tilde{x}_{ij}$ denotes the corresponding HFLTS of x_{ij}.

2) Second, it is computed the correspondent fuzzy envelop of $\tilde{x}_{ij}$, according to Eq. (3),

$$env_F(\tilde{x}_{ij}) = \bar{x}_{ij}(\bar{x}_{ij}^1, \bar{x}_{ij}^2, \bar{x}_{ij}^3, \bar{x}_{ij}^4) \tag{9}$$

Based on Eqs. (8)-(9), the linguistic expressions provided by DM are transformed into a fuzzy domain, denoted $\bar{X} = (\bar{x}_{ij})_{m\times n}$, where $\bar{x}_{ij} = (\bar{x}_{ij}^1, \bar{x}_{ij}^2, \bar{x}_{ij}^3, \bar{x}_{ij}^4)$, $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$. Therefore, both linguistic terms and expressions are represented by means of fuzzy trapezoidal membership functions.

D. Selection process-fuzzy TODIM method

As it was pointed out previously, the DM is usually bounded cognition, and his/her psychological behavior is very crucial to deal with the EE successfully. To address such issue, this contribution takes into account DM's psychological behavior by means of fuzzy TODIM method dealing with the problem defined in a fuzzy environment. Therefore the fuzzy TODIM method introduced in section II B is adapted to our framework, such that the step 1 is removed, because the matrix, $\bar{X} = (\bar{x}_{ij})_{m\times n}$, is already normalized and the step 3 is modified as follows to deal with EDM problems:

Step 3: The dominance degree, $\Phi_j(a_i, a_k)$, of a_i over the rest of alternatives $a_k (k = 1, 2, \ldots, m)$ regarding c_j is calculated, i.e.,

$$\Phi_j(p_i, p_k) = \begin{cases} \sqrt{d(\bar{x}_{ij}, \bar{x}_{kj}) w_{jr} / (\sum_{j=1}^{n} w_{jr})}, \\ \tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) \geq 0 \\ \\ -\frac{1}{\theta}\sqrt{d(\bar{x}_{ij}, \bar{x}_{kj}) (\sum_{j=1}^{n} w_{jr}) / w_{jr}}, \\ \tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) < 0 \end{cases} \tag{10}$$

where $\bar{x}_{ij}$ denotes the trapezoidal fuzzy number $\bar{x}_{ij} = (\bar{x}_{ij}^1, \bar{x}_{ij}^2, \bar{x}_{ij}^3, \bar{x}_{ij}^4)$ that represents the information about the *i-th* alternative concerning the *j-th* criterion.

$\tilde{m}(\bar{x}_{ij})$ denotes the defuzzied value of the fuzzy number $\bar{x}_{ij}$, where $\tilde{m}(\bar{x}_{ij}) = \frac{\bar{x}_{ij}^1 + 2\bar{x}_{ij}^2 + 2\bar{x}_{ij}^3 + \bar{x}_{ij}^4}{6}$ [21].

$d(\bar{x}_{ij}, \bar{x}_{kj})$ denotes the gains or losses of the a_i over a_k regarding c_j, where $d(\bar{x}_{ij}, \bar{x}_{kj}) = \sqrt{\sum_{z=1}^{4} (\bar{x}_{ij}^z - \bar{x}_{kj}^z)^2}$.

For benefit criteria, $d(\bar{x}_{ij}, \bar{x}_{kj})$ denotes the gains with $\tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) \geq 0$ or losses with $\tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) < 0$, respectively. $\Phi_j(a_i, a_k)$ can be expressed as:

$$\Phi_j(p_i, p_k) = \begin{cases} \sqrt{d(\bar{x}_{ij}, \bar{x}_{kj}) w_{jr} / (\sum_{j=1}^{n} w_{jr})}, \\ \tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) \geq 0 \\ \\ -\frac{1}{\theta}\sqrt{d(\bar{x}_{ij}, \bar{x}_{kj}) (\sum_{j=1}^{n} w_{jr}) / w_{jr}}, \\ \tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) < 0 \end{cases} \tag{11}$$

For cost criteria, $d(\bar{x}_{ij}, \bar{x}_{kj})$ denotes the gains with $\tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) \leq 0$ or losses with $\tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) > 0$, respectively. $\Phi_j(a_i, a_k)$ can be expressed as:

$$\Phi_j(p_i, p_k) = \begin{cases} \sqrt{d(\bar{x}_{ij}, \bar{x}_{kj}) w_{jr} / (\sum_{j=1}^{n} w_{jr})}, \\ \tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) \leq 0 \\ \\ -\frac{1}{\theta}\sqrt{d(\bar{x}_{ij}, \bar{x}_{kj}) (\sum_{j=1}^{n} w_{jr}) / w_{jr}}, \\ \tilde{m}(\bar{x}_{ij}) - \tilde{m}(\bar{x}_{kj}) > 0 \end{cases} \tag{12}$$

IV. CASE STUDY

In order to demonstrate the applicability of the proposed EDM method, this section presents an example adapted from [1] "*a barrier lake emergency*".

A. Decision Framework

Due to such emergency situation, the local government organized people located in upstream and downstream areas to evacuate them to safety areas. And it is then defined the following decision framework with five emergency alternatives $A = \{a_1, a_2, a_3, a_4, a_5\}$ described by five criteria $C = \{c_1, c_2, c_3, c_4, c_5\}$, which are given in Tables I and II, respectively.

The linguistic term sets, S_1 and S_2 introduced in Table II, are shown in Fig. 3.

B. Gathering assessments

TABLE I
DESCRIPTION OF ALTERNATIVES

Alternatives	Description
a_1	To implement small-scale of man-made blasting and excavate the flood discharge grooves to increase the discharged water amount of the barrier lake.
a_2	To decrease the risk, the joint scheduling of the reservoirs and hydropower stations in the upstream and downstream areas are carried out.
a_3	To implement large-scale blasting and mobilize different types heavy machinery to reduce the dam break risk of the barrier lake as much as possible.
a_4	The joint scheduling of the reservoirs and hydropower stations works together with the implementation of large-scale blasting to reduce the risk.
a_5	To mobilize trucks and heavy machinery to strengthen the dam body of barrier lake.

TABLE II
DESCRIPTION OF CRITERIA

Criteria	Description
People affected (c_1)	It means the alternative a_i will protect the people located in the upstream and downstream areas to avoid the degree of impacts, S_1 ={None(N), Very Low(VL), Low(L), Medium(M), High(H), Very High(VH), Absolutely High(AH)}.
Environment affected (c_2)	It is evaluated by DM using S_2={None(N), Very Low Seriously(VLS), Low Seriously(LS), Medium(M), High Seriously(HS), Very High Seriously(VHS), Absolutely High Seriously(AHS)}.
Social impacts (c_3)	It means that if the alternative a_i is implemented, it will generate repercussions from the masses, the linguistic terms are same to S_2.
Property loss (c_4)	It means that the alternative a_i can protect the degree of property losses caused by EE, directly and indirectly , the linguistic terms are same to S_1.
Alternative cost (c_5)	It means that the whole cost of alternative a_i, the linguistic terms are same to S_1.

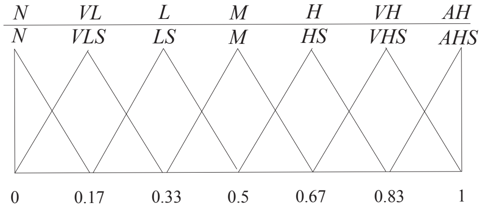

Fig. 3. Linguistic term sets for S_1 and S_2

DM provides his/her assessments over the five emergency alternatives regarding five criteria. The information matrix, $X = (x_{ij})_{m\times n}$, is gathered, see Table III (”bt” means ”between”).

C. Unification process

Based on Eq. (8), the information matrix, $X = (x_{ij})_{m\times n}$, is transformed into, $\tilde{X} = (\tilde{x}_{ij})_{m\times n}$, see Table IV.

And then, the fuzzy matrix, $\bar{X} = (\bar{x}_{ij})_{m\times n}$ can be obtained based on $\tilde{X}$, according to Eq. (9), see Table V.

TABLE III
INFORMATION MATRIX X

	C				
A	c_1	c_2	c_3	c_4	c_5
a_1	L	bt M and HS	LS	H	M
a_2	M	At most M	bt M and HS	bt H and VH	H
a_3	At most M	HS	M	VH	bt M and H
a_4	bt H and VH	At most LS	HS	bt H and VH	bt H and VH
a_5	H	bt HS and VHS	At least HS	H	At least H

TABLE VI
OVERALL DOMINANCE DEGREE OF EACH ALTERNATIVE

$\eta(a_i)$	Values	Rank
$\eta(a_1)$	0.840	3
$\eta(a_2)$	0.947	2
$\eta(a_3)$	0.700	4
$\eta(a_4)$	**1.0**	**1**
$\eta(a_5)$	0	5

D. Selection process-fuzzy TODIM method

The criteria weights $w_c = (w_{c_1}, w_{c_2}, w_{c_3}, w_{c_4}, w_{c_5})$ are provided by DM, i.e., $w_c = (0.3, 0.2, 0.2, 0.15, 0.15)$. The overall dominance degree of each alternative, $\eta(a_i)$, is calculated by fuzzy TODIM method, the results are shown in Table VI.

According to Table VI, the ranking of alternatives can be obtained:

$$a_4 \succ a_2 \succ a_1 \succ a_3 \succ a_5$$

Finally, the DM can select a_4 as the best alternative to cope with the EE.

V. CONCLUSIONS

Hesitancy is a common performance in human beings daily life, especially in EDM situations featured by strong time constraints and high potentially serious consequences. However, such interesting issue is neglected in current EDM approaches. Due to the urgent time requirements and high-risk results of EDM, the DM is usually bounded cognition, and his/her psychological behavior is very important in the decision process, such issue has already considered in current EDM approaches, however, they are not appropriate to deal with the DM’s psychological behavior within a fuzzy domain. To manage these limitations, this contribution proposes a hesitant fuzzy linguistic model based on fuzzy TODIM method for EDM dealing with the linguistic terms including DM’s hesitation and considering DM’s bounded cognition and psychological behavior under fuzzy environment. A case study about the barrier lake emergency adapted from current study is provided to demonstrate the applicability of the hesitant fuzzy linguistic model for EDM.

It is expected that the proposed EDM method may have potential applications in real world to help DM to deal with different types of EEs.

Future research could be the use of computer science and Internet technology for supporting the EDM based on big data.

TABLE IV
INFORMATION MATRIX $\tilde{X}$

A	C				
	c_1	c_2	c_3	c_4	c_5
a_1	L	(M,HS)	LS	H	M
a_2	M	(N,VLS,LS,M)	(M,HS)	(H,VH)	H
a_3	(N,VL,L,M)	HS	M	VH	(M,H)
a_4	(H,VH)	(N,VLS,LS)	HS	(H,VH)	(H,VH)
a_5	H	(HS,VHS)	(HS,VHS,AHS)	H	(H,VH,AH)

TABLE V
FUZZY MATRIX $\bar{X}$

A	C				
	c_1	c_2	c_3	c_4	c_5
a_1	(0.17,0.33,0.33,0.5)	(0.34,0.5,0.67,0.84)	(0.17,0.33,0.33,0.5)	(0.5,0.67,0.67,0.83)	(0.33,0.5,0.5,0.67)
a_2	(0.33,0.5,0.5,0.67)	(0,0,0.36,0.67)	(0.34,0.5,0.67,0.84)	(0.5,0.67,0.84,1.0)	(0.5,0.67,0.67,0.83)
a_3	(0,0,0.36,0.67)	(0.5,0.67,0.67,0.83)	(0.33,0.5,0.5,0.67)	(0.67,0.83,0.83,1)	(0.34,0.5,0.67,0.84)
a_4	(0.5,0.67,0.84,1.0)	(0,0,0.15,0.5)	(0.5,0.67,0.67,0.83)	(0.5,0.67,0.84,1.0)	(0.5,0.67,0.84,1.0)
a_5	(0.5,0.67,0.67,0.83)	(0.5,0.67,0.84,1.0)	(0.5,0.86,1.0,1.0)	(0.5,0.67,0.67,0.83)	(0.5,0.86,1.0,1.0)

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