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An approach to evaluation of emergency plans for unconventional emergency events based on soft fuzzy rough set

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Abstract
Purpose – The purpose of this paper is to present a new method for evaluation of emergency plans for unconventional emergency events by using the soft fuzzy rough set theory and methodology.
Design/methodology/approach – In response to the problems of insufficient risk identification, incomplete and inaccurate data and different preference of decision makers, a new model for emergency plan evaluation is established by combining soft set theory with classical fuzzy rough set theory. Moreover, by combining the TOPSIS method with soft fuzzy rough set theory, the score value of the soft fuzzy lower and upper approximation is defined for the optimal object and the worst object. Finally, emergency plans are comprehensively evaluated according to the soft close degree of the soft fuzzy rough set theory.
Findings – This paper presents a new perspective on emergency management decision making in unconventional emergency events. Also, the paper provides an effective model for evaluating emergency plans for unconventional events.
Originality/value – The paper contributes to decision making in emergency management of unconventional emergency events. The model is useful for dealing with decision making with uncertain information.
Keywords Rough set, Emergency plans evaluation, Optimal object plan, Soft close degree, Soft fuzzy rough set
Paper type Research paper

1. Introduction
In recent years, all kinds of natural disasters, such as earthquakes, floods, droughts, hurricanes, landslides, fires, tsunamis, extreme cold and cyclones have killed thousands of people and destroyed millions of dollars worth of habitats and assets (Bozorgi-Amiri *et al.*, 2013; Wassenhove, 2006). For example, a major tsunami affected 12 countries in 2004; massive earthquakes struck Bam, Iran in 2003, Pakistan in 2005, China in 2008, 2010 and 2013 and Haiti in 2010; and an extensive flood devastated Pakistan and China in 2010. The rapid growth in world population and increased human concentrations in

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dangerous environments have led to increases in both the frequency and severity of natural disasters. Consequently, the number of people affected by natural disasters continues to rise (Haghani and Afshar, 2009; Bozorgi-Amiri *et al.*, 2013). According to incomplete statistics, each year unconventional emergency events cause a loss of 5 percent of the total GDP in China (Zeng *et al.*, 2009).

Faced with unconventional emergency events, human beings must be proactive in dealing with them, including establishing comprehensive emergency preparedness systems and emergency decision-making theory and methods (Cosgrave, 1996). A major feature of unconventional emergency events is that they often occur unexpectedly, as in the case of terrorist attacks, earthquakes and so on. Technical limitations and other factors make it difficult to accurately predict crises. Thus, uncertainty about the time of occurrence and insufficient information about the severity and extent of the impact constitute the basic features of unconventional emergency events. This uncertainty makes it difficult to describe unconventional emergency events precisely with a quantitative model and theory. Timely and effective decision making is essential in aiding people who are made vulnerable by natural disasters, while delayed and incorrect decision making may render emergency response ineffective and result in increased suffering. Therefore, it is necessary to establish a scientific and effective theory and methodology for decision making in response to unconventional emergency events.

To address these problems, many quantitative approaches have been used in evaluation studies of emergency planning. These include the fuzzy comprehensive evaluation (Yang *et al.*, 2007), the analytic hierarchy process (AHP) (Pauwels *et al.*, 2000) and data envelopment analysis (Chen *et al.*, 2010). Also, mathematical theories such as multi-attribute (or multi-criteria) decision making (Chen and Hwang, 1992), multi-objective programming and optimization of classic operations research (Keeneyr and Raiffa, 1993) have been used in emergency decision-making research. There is also a group decision-making (GDM) approach to emergency management (Ju and Wang, 2012; Levy and Taji, 2007; Mendonca *et al.*, 2006; Yu and Lai, 2011; Zografos *et al.*, 2000). Yu and Lai (2011) proposed a distance-based GDM methodology to solve unconventional multi-person, multi-criteria emergency decision-making problems. They first construct a framework of GDM. Then a standard multi-criteria decision-making process is performed on specific emergency decision-making problems. Levy and Taji (2007) proposed a group analytic network process to construct a GDSS to support hazard planning and emergency management under incomplete information. Zografos *et al.* (2000) presented a methodological framework for developing a hazardous material emergency response decision support system to manage emergency response operations for large-scale industrial accidents in Western Attica, Greece. Similarly, Mendonca *et al.* (2006) designed a gaming simulation to assess GDSS for emergency management. Ju and Wang (2012) presented the DS/AHP method and extended the TOPSIS method to solve group multi-criteria decision making problems with incomplete information and then applied these methods to the evaluation of alternatives during an emergency. Hector *et al.* (2013) developed a mathematical formulation that combines an integer programming model representing location and dispatching decisions for emergency medical services for an unconventional emergency event. Sun *et al.* (2013) presented a fuzzy rough set approach to emergency material demand prediction over two universes.

All the existing studies about emergency decision making provide effective decision-making models and methods by using different mathematical theories and tools. One of these approaches is known as plans-based decision making (Jenkins, 2000; Dyer *et al.*, 2005). This idea depends on emergency preparedness plans which are pre-established according to the characteristics of different unconventional emergency events. So, a new problem in emergency decision making is how to evaluate pre-established emergency plans and then select the optimal one to handle concrete emergency events. Several matured quantitative approaches such as fuzzy comprehensive evaluation (Zhang *et al.*, 2004), AHP or various improved AHP methods (Luo *et al.*, 2008) and DEA methods (Zhu *et al.*, 2011) have been developed to evaluate emergency plans. Though one can obtain reasonable evaluation results by using the above methods, there may be some limitations, such as how to select and define the evaluation function, the inconsistency of the weights for the evaluation indices given by experts and the reliability of the results when too many evaluation indices are included.

Considering the existing results, this paper attempts to present a new approach to emergency plans evaluation by using the soft fuzzy rough set approach. By combining the TOPSIS method with soft fuzzy rough set theory, we define the score value of soft fuzzy lower and upper approximations for the optimal plan and the worst plan. Then the comprehension evaluation result for every emergency plan is given according to the soft close degree of soft fuzzy rough set theory. The method of soft fuzzy rough set for emergency plans evaluation does not depend on the score values given by experts and does not require computing the weights of the evaluation indices. Moreover, the optimal and worst emergency plans were determined based only on characteristics of the pre-established emergency plans, without the need for additional information which may be inaccurate or incomplete during the actual emergency.

The paper is organized as follows. Section 2 briefly introduces soft set theory and soft fuzzy rough set theory. Section 3 gives the model and method of evaluation for emergency plans for unconventional emergency events. At the same time, we propose an algorithm for this method of evaluation of emergency plans. In Section 4, we study an applied numerical example and verify the validity of the theory and approaches proposed in this paper. We conclude our research and propose further research directions in Section 5.

2. Preliminaries

In this section, we review some basic concepts to be used in this paper, such as soft set and soft fuzzy rough set.

2.1 Soft set theory

Soft set theory was originally proposed by Molodtsov (1999) as a new mathematical tool for dealing with uncertainties that was free from the difficulties that have troubled the usual theoretical approaches. As reviewed in Molodtsov (1999), Maji and Roy (2002) and Maji *et al.* (2001, 2003), a wide range of applications of soft set have been developed in many different fields including the smoothness of functions, game theory, operations research, Riemann integration, Perron integration, probability theory and measurement theory. Recently, there has been a rapid growth of interest in both theory and application of soft set. Meanwhile, there also have been many practical applications of soft set theory, especially the use of soft set in decision making (Chen *et al.*, 2005; Majumdara and Samantab, 2010). In the following, we give the basic concept of the soft set theory.

Throughout in this paper U denotes a non-empty finite set unless stated otherwise.

Let U be a universe of objects and E be the set of parameters in relation to objects in U. Let $P(U)$ denote the power set of U (Molodtsov, 1999):

Definition 2.1 (Molodtsov, 1999) A pair (F, E) is called a soft set over U, where F is a mapping given by $F: E \to P(U)$.

By definition, a soft set (F, E) over the universe U can be regarded as a parameterized family of subsets of the universe U, which gives an approximation (a soft description) of the objects in U. As pointed out in Maji *et al.* (2003), for any parameter $\varepsilon \in A$, the subset $F(\varepsilon) \subseteq U$ may be considered as the set of ε-approximate elements in the soft set (F, E). It is worth noting that $F(\varepsilon)$ may be arbitrary; some of the sets may be empty and some may have non-empty intersections (Maji *et al.*, 2003).

For illustration, we consider an example to show the concepts based on Molodtsov (1999):

Example 2.1 Suppose the following $U = \{h_1, h_2, h_3, h_4, h_5, h_6\}$ is a set of houses under consideration. $E = \{e_1, e_2, e_3, e_4, e_5\}$ is the set of parameters. Each parameter is a word or phrase, where e_1 stands for the parameter "expensive", e_2 stands for the parameter "beautiful", e_3 stands for the parameter "wooden", e_4 stands for the parameter "cheap", e_5 stands for the parameter "in green surroundings".

In this case, to define a soft set means to point out expensive houses, beautiful houses and so on. The soft set (F, E) describes the "attractiveness of the houses," one of which Mr X is going to buy. Suppose that $F(e_1) = \{h_2, h_4\}$, $F(e_2) = \{h_1, h_3\}$, $F(e_3) = \{h_3, h_4, h_5\}$, $F(e_4) = \{h_1, h_3, h_5\}$, $F(e_5) = \{h_1\}$. Then $F(e_1)$ represents h_2 and h_4, which are expensive houses. A similar interpretation can be made for other houses.

Maji *et al.* (2001) studied hybrid structures involving both fuzzy sets and soft sets, and introduced the concept of fuzzy soft sets, which can be seen as a fuzzy generalization of soft sets:

Definition 2.2 (Maji *et al.*, 2001) Let $F(U)$ be the set of all fuzzy subsets in a universe U. Let E be a set of parameters. A pair $(\tilde{F}, E)$ is called a fuzzy soft set over U, where $\tilde{F}$ is a mapping given by $\tilde{F}: F \to F(U)$.

For example, $\tilde{F}(e_2) = 0.6/h_1 + 1.0/h_2 + 0.2/h_3 + 0.5/h_4 + 0.8/h_5 + 0.9/h_6$ is the fuzzy description of all six houses in universe U with respect to the parameter "Beautiful (e_2)."

2.2 Soft fuzzy rough set theory

From the definition of Molodtsov's soft set, all the objects which have some concrete characteristics in the universe are described by determining the object set which corresponds to any parameter $e \in E$ of the parameter set E. As in the Example 2.1, the object set $F(expensive) = \{h_3, h_4, h_5\}$ shows that house 2, house 4 and house 6 have the characteristic of "Expensive." Conversely, for a specific house $h_i \in U$, one wants to know the features of the house $h_i \in U$. Based on this consideration, Sun and Ma (2014) first introduced the concept of pseudo soft set over a universe:

Definition 2.3 (Sun and Ma, 2014) A pair (F^{-1}, E) is called a pseudo soft set over universe U if and only if F^{-1} is a mapping of U into the set of all subsets in the parameter set E, where F^{-1} is a mapping given by $F^{-1}: U \to P(E)$, where $P(E)$ denotes all subsets of parameter set E.

It is easy to find that $F^{-1}(h_1) = \{e_2, e_4, e_5\}$ shows the characteristics of house h_1 including "Beautiful," "Cheap" and "In green surroundings."

Similarly, the pseudo fuzzy soft set is defined as follows:

Definition 2.4 (Sun and Ma, 2014) A pair $(\tilde{F}^{-1}, E)$ is called a pseudo fuzzy soft set over U if and only if $\tilde{F}^{-1}$ is a mapping of U onto the set of all fuzzy subsets of the set E, where $\tilde{F}^{-1}$ is a mapping given by $\tilde{F}^{-1}$: $U \to F(E)$. That is, $\tilde{F}^{-1}(h)(e) \in [0,1], \forall h \in U, e \in E$.

Clearly, from the definition of pseudo fuzzy soft set, we know that the pseudo fuzzy mapping $\tilde{F}^{-1} : U \to F(E)$ is a binary fuzzy relation defined between the universe U and the parameter set E. That is, for any $h_i \in U$, $e_j \in E$, $\tilde{F}^{-1}(h_i)(e_j) \in F(U \times E)$.

Based on the pseudo fuzzy binary relation $\tilde{F}^{-1}$, the soft fuzzy rough set (Sun and Ma, 2014) can be defined as follows.

Let $(\tilde{F}^{-1}, E)$ be a pseudo fuzzy soft set over U. We call the triple $(U, E, \tilde{F}^{-1})$ the soft fuzzy approximation space. For any $A \in F(E)$,the lower and upper approximations of A, $\underline{F}(A)$ and $\overline{F}(A)$ with respect to the soft fuzzy approximation space $(U, E, \tilde{F}^{-1})$ are fuzzy sets of U whose membership functions for each $x \in U$, are defined, respectively, by:

$$\underline{F}(A)(x) = \wedge_{y \in E}\left[\left(1-\tilde{F}^{-1}(x)(y)\right) \vee A(y)\right], \quad x \in U,$$

$$\overline{F}(A)(x) = \vee_{y \in E}\left[\tilde{F}^{-1}(x)(y) \wedge A(y)\right], \quad x \in U.$$

Moreover, the pair $\left(\underline{F}(A), \overline{F}(A)\right)$ is referred to as a soft fuzzy rough set over universe U.

A more detailed discussion of the properties of the soft fuzzy rough set was given by Sun and Ma (2014). In the following, we focus on the method of emergency decision making based on soft fuzzy rough set.

3. An approach to evaluation of emergency plans based on soft fuzzy rough set

Unconventional emergency events are a complex system with the characteristics of changeable mechanisms in how they occur and develop. Significant characteristics include time constraints, insufficient information and limited resources. Decision makers must act quickly even though the information is usually insufficient. That is, an emergency decision must often be made in a short period of time using partial or inaccurate information, especially in the early stages of the disaster. So, all possible emergency plans are established in advance based on the characteristics of similar events. Then the decision makers can make a quick decision when the unconventional emergency events occur by selecting one of the established emergency plans. So, a key issue is how to select the optimal emergency plan. Therefore, it is necessary to evaluate all the emergency plans. This can not only can help the decision makers select the optimal plan but also can point out limitations and help improve the plans.

This section will present a new approach to evaluation of emergency plans by combining soft fuzzy rough set theory with the TOPSIS method. First, we present the quantitative description of the emergency plans by using the soft fuzzy set. Then we can obtain the optimal and worst object emergency plans based on the principle of TOPSIS. Second, we compute the lower and upper approximations of the optimal and worst emergency plans about the soft fuzzy approximation space $(U, E, \tilde{F}^{-1})$. Finally, we can give a comprehensive evaluation by using the concept of soft close degree.

3.1 The model

Let $U = \{h_1, h_2, \ldots, h_m\}$ be m emergency plans established in advance of an unconventional emergency event. The parameter set $E = \{e_1, e_2, \ldots, e_n\}$ comprises the characteristics with uncertain information about the emergency plans. $\tilde{F}^{-1} \in F(U \times E)$ is the fuzzy binary mapping from the emergency plans set U to parameter set E. That is, $\tilde{F}^{-1}(h_i)(e_j) \in [0,1] (\forall h_i \in U, e_j \in E)$ represents the quantitative description of emergency plan h_i about the characteristic e_j, i.e., the fuzzy membership degree of h_i about e_j (in general, the characteristics of an emergency plan can be seen as a profitable index, which means the greater the value, the more important the characteristic, and vice versa). Thus, we construct a soft fuzzy information system $(U, E, \tilde{F}^{-1})$ for the evaluation of emergency plans.

Then, we give the optimal object emergency plan and the worst emergency plan (denoted as A^+ and A^-) of the m emergency plans over universe U as follows, respectively:

$$A^+ = \sum \frac{\max \tilde{F}(e_j)}{e_j}, \quad \forall e_j \in E, \ A^+(e_j) = \max\left\{\tilde{F}(e_j)(h_i) \middle| h_i \in U\right\}, \tag{1}$$

$$A^- = \sum \frac{\min \tilde{F}(e_j)}{e_j}, \quad \forall e_j \in E, \ A^-(e_j) = \min\left\{\tilde{F}(e_j)(h_i) \middle| h_i \in U\right\}, \tag{2}$$

It is easy to know that A^+ and A^- are established by taking the maximum value and minimum value for the fuzzy soft set $(\tilde{F}, E)$ about the characteristic factor $\forall e_j \in E$. Moreover, there is $A^+, A^- \in F(E)$.

In the following, we present the steps of the evaluation model in detail.

First, we can calculate the lower approximation $\underline{F}(A^+)(\underline{F}(A^-))$ and upper approximation $\overline{F}(A^+)$ $\left(\overline{F}(A^-)\right)$ of the object plans A^+ and A^- with respect to the soft fuzzy information system$(U, E, \tilde{F}^{-1})$ as follows, respectively:

$$\underline{F}(A^+)(h_i) = \underset{e_j \in E}{\wedge}\left[\left(1 - \tilde{F}^{-1}(h_i)(e_j)\right) \vee A^+(e_j)\right], \quad h_i \in U,$$

$$\overline{F}(A^+)(h_i) = \underset{e_j \in E}{\vee}\left[\tilde{F}^{-1}(h_i)(e_j) \wedge A^-(e_j)\right], \quad h_i \in U,$$

and:

$$\underline{F}(A^-)(h_i) = \underset{e_j \in E}{\wedge}\left[\left(1 - \tilde{F}^{-1}(h_i)(e_j)\right) \vee A^-(e_j)\right], \quad h_i \in U,$$

$$\overline{F}(A^-)(h_i) = \underset{e_j \in E}{\vee}\left[\tilde{F}^{-1}(h_i)(e_j) \wedge A^-(e_j)\right], \quad h_i \in U,$$

where $i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$.

By the basic theory of soft set, we define the following concepts:

Definition 3.1 Let $(U, E, \tilde{F}^{-1})$ be a soft fuzzy approximation space. For any $A \in F(U)$, we call:

$$\sigma(A) = \underline{F}(A)(x) + \overline{F}(A)(x), \; x \in U, \tag{3}$$

the score function of A with respect to the soft fuzzy approximation space.

Second, from the Definition 3.1, we calculate the score value for any emergency plan $h_i \in U$ with respect to the object plans A^+ and A^- as follows, respectively:

$$\sigma_i(A^+) = \underline{F}(A^+)(h_i) + \overline{F}(A^+)(h_i), \quad h_i \in U$$

$$\sigma_i(A^-) = \underline{F}(A^-)(h_i) + \overline{F}(A^-)(h_i), \quad h_i \in U$$

In the following, we present the concept of soft close degree over soft fuzzy approximation space:

Definition 3.2 Let $(U, E, \tilde{F}^{-1})$ be a soft fuzzy information system for the evaluation of emergency plans. For the object plans A^+ and A^-, we call:

$$\sigma_i = \sigma_i(A^+) - \sigma_i(A^-)$$

the soft close degree of the ith emergency plan h_i about $(U, E, \tilde{F}^{-1})$.

Remark 3.1 From the properties of soft fuzzy rough set (Sun and Ma, 2014), for any $A_1, A_2 \in F(E)$ which satisfies $A_1 \subseteq A_2$, $\underline{F}(A_1) \subseteq \underline{F}(A_2)$ and $\overline{F}(A_1) \subseteq \overline{F}(A_2)$ hold. It can be easily seen that the object plans $A^+$and A^- satisfy $A^- \subseteq A^+$, therefore, $\sigma_i(A^+) \geqslant \sigma_i(A^-)$ for any $h_i \in U$. So, $\sigma_i \geqslant 0$.

Therefore, the above definition of the soft close degree is reasonable.

Third, calculating the soft close degree for every emergency plan over universe U with respect to object plans A^+ and A^-, we have:

$$\sigma_i = \sigma_i(A^+) - \sigma_i(A^-) \tag{4}$$

Finally, we can present a comprehensive evaluation and ranking for all the emergency plans for a given emergency event according to the values of soft close degree.

3.2 The algorithm of the model for the evaluation of emergency plans

In this section, we present an algorithm for the evaluation of emergency plans for unconventional emergency plans based on soft fuzzy rough set:

Input: soft fuzzy information system for the evaluation of emergency plans $(U, E, \tilde{F}^{-1})$.

Output: comprehensive evaluation and ranking of emergency plans.

Step 1: computing the optimal object plan A^+ and the worst object plan A^- for all the emergency plans.

Step 2: computing the lower and upper approximations of object plans A^+ and A^- with respect to $(U, E, \tilde{F}^{-1})$.

Step 3: computing the score value $\sigma_i(A^+)$ and $\sigma_i(A^-)$ of object plans A^+ and A^-.

Step 4: computing the soft close degree σ_I for every plan.

Step 5: presenting the comprehensive evaluation and ranking of all the emergency plans.

4. A numerical test of the model

In this section, we will show the basic principle and steps of the model of evaluation of emergency plans by using a realistic numerical example. Suppose $U = \{h_1, h_2, h_3, h_4, h_5, h_6\}$ are six emergency plans established in advance for a certain unconventional emergency event such as an earthquake or terrorist attack.

In general, the characteristics of emergency plans should include the following aspects.

4.1 Comprehensiveness and completeness (e_1)

As is well known, the randomness and uncertainty of the occurrence of unconventional emergency events are their most striking features. So, emergency plans should consider various scenarios of unconventional emergency events as much as possible; then they can cope with all possible cases. If an emergency plan is incomplete, this could affect the response capacity of decision makers when they face a real emergency.

4.2 Feasibility (e_2)

The feasibility of an emergency plan directly affects the speed and effectiveness of dealing with the emergency. Moreover, it also may delay the response.

4.3 Timely response (e_3)

A timely response to unconventional emergency events can decrease the loss of lives and property as much as possible. Meanwhile, timely response also can prevent the spread of the effects of the emergency to a larger region.

4.4 Budgeting the cost (e_4)

Emergency plans should not disregard cost. That is, ensuring reasonable expenses in emergency plans is an important factor in evaluating the plan.

4.5 Ability to adjust plan (e_5)

In general, new emergency plans are established based on events that occurred in the past. Thus, a plan might not be suitable to new scenarios. Therefore, emergency plans established in advance should be adjustable in order to achieve optimal results during implementation.

4.6 Effectiveness of handling (e_6)

This index reflects to what extent the emergency plans can be implemented for new events under the condition of limited resources.

4.7 Technical level of the equipment (e_7)

As is well known, an advanced technical level of equipment is one factor determining the effectiveness of emergency plans.

Therefore, $E = \{$Comprehensiveness and completeness (e_1), Feasibility (e_2), Timely Response (e_3), Budgeting the cost (e_4), Ability to adjust the plan (e_5), Effectiveness of handling (e_6) and Technical level of the equipment (e_7)$\}$ make up the basic description of emergency plans; these seven aspects are described using linguistic information. So, the pseudo fuzzy binary mapping $\tilde{F}^{-1} \in F(U \times E)$ gives a quantitative description of every emergency plan with respect to the seven characteristics (i.e. the fuzzy membership degree). That is, $\tilde{F}^{-1}(h_i)(e_j) \in [0, 1]$ is the membership degree of every emergency plan $h_i (i = 1,2, \ldots 6)$ with respect to characteristic e_j (as noted above, the characteristics of an earthquake plan, for example, can be seen as a profitable index, which means the greater the value, the more important the characteristic. For example, for the factor e_2, if $\tilde{F}^{-1}(h_2)(e_2) = 0.6$ and $\tilde{F}^{-1}(h_3)(e_2) = 0.8$, then emergency plan h_3 is more feasible than emergency plan h_2).

The quantitative descriptions of all the emergency plans with respect to these characteristics are presented in Table I (soft fuzzy information system $(U, E, \tilde{F}^{-1})$).

From Table I, we can obtain the object plan A^+ and A^-, respectively, according to formulas (1) and (2) given in Section 3, as follows:

$$A^+ = \frac{0.7}{e_1} + \frac{0.5}{e_2} + \frac{0.5}{e_3} + \frac{0.4}{e_4} + \frac{0.5}{e_5} + \frac{0.5}{e_6} + \frac{0.6}{e_7},$$

$$A^- = \frac{0.2}{e_1} + \frac{0.1}{e_2} + \frac{0.2}{e_3} + \frac{0.1}{e_4} + \frac{0.1}{e_5} + \frac{0.1}{e_6} + \frac{0.3}{e_7}.$$

Next, we can calculate the lower and upper approximations of object plan A^+ and A^-, i.e., the soft close degree for every emergency plan by using formulas (3) and (4) given in Section 3.

The results are presented in the following Table II.

Finally, the comprehensive evaluation results for six emergency plans can be given according to the value of soft close degree σ_i as follows:

$$h_4 > h_1 = h_3 > h_2 = h_5 = h_6$$

The evaluation results show that the six emergency plans are divided into three levels: the best plan is h_4; h_1 and h_3 are the second level; and the third level is h_2, h_5 and h_6.

U/E	e1	e2	e3	e4	e5	e6	e7
h_1	0.3	0.1	0.4	0.4	0.1	0.1	0.5
h_2	0.3	0.3	0.5	0.1	0.3	0.1	0.5
h_3	0.4	0.3	0.5	0.1	0.3	0.1	0.6
h_4	0.7	0.4	0.2	0.3	0.2	0.1	0.3
h_5	0.2	0.5	0.2	0.2	0.5	0.5	0.4
h_6	0.3	0.5	0.2	0.4	0.2	0.3	0.3

Table I. Soft fuzzy information system $(U,E,\tilde{F}^{-1})$

U	h_1	h_2	h_3	h_4	h_5	h_6
$\overline{F}(A^+)$	0.6	0.5	0.6	0.7	0.5	0.5
$\underline{F}(A^+)$	0.6	0.5	0.5	0.6	0.5	0.5
$\sigma_i(A^+)$	1.2	1.0	1.1	1.3	1.0	1.0
$\overline{F}(A^-)$	0.3	0.3	0.3	0.3	0.3	0.3
$\underline{F}(A^-)$	0.5	0.5	0.4	0.3	0.5	0.5
$\sigma_i(A^-)$	0.8	0.8	0.7	0.6	0.8	0.8
σ_i	0.4	0.2	0.4	0.7	0.2	0.2

Table II. The evaluation model for emergency plans

The emergency plans h_1 and h_3 are indistinguishable based on the current characteristics; the same is true for h_2, h_5 and h_6.

Therefore, we obtain comprehensive evaluation results for the six emergency plans by using the soft fuzzy rough set theory. Then the decision makers can select optimal and adaptable plans to handle unconventional emergency events in practice.

In the paper presented, a new approach to evaluate emergency plans for unconventional emergency events by using the soft fuzzy rough set theory has been established, which can provide a new study angle on emergency decision making for unconventional emergency events. As far as the methods for evaluation of emergency plans for unconventional emergency event are concerned, existing similar approaches include fuzzy comprehension assessment (Zhang *et al.*, 2004), AHP (Pauwels *et al.*, 2000) and multiple attribute GDM (Sun *et al.*, 2005), and etc. Though the existing studies provide useful methods, there are some limitations. For example, there may arise an inconsistency in judgment among experts because there are too many evaluation indices (more than nine indices) in the methods of fuzzy comprehension assessment (Zhang *et al.*, 2004) and AHP (Pauwels *et al.*, 2000). Similarly, in the method of multiple attribute GDM, different results for the same emergency plans may be obtained based on the same evaluation method due to the use of different aggregation operators for the group preference judgment (Sun *et al.*, 2005). By contrast, for the method given in this paper, both the lower and upper approximations of the optimal object emergency plan and the worst emergency plan are calculated by using available information about actual emergency events. Then, the ranking of all candidate plans for unconventional emergency events is given by using the values of lower and upper approximations. So, the proposed method can avoid the limitations in the existing literature (Pauwels *et al.*, 2000; Zhang *et al.*, 2004; Sun *et al.*, 2005).

5. Conclusions and remarks

Emergency management has become a growing research field as a result of the increasing number of unconventional emergency events. As the core issue of emergency management, emergency decision making has been developed into a framework incorporating multiple disciplines, decision theories and methodologies. As is well known, emergency decision making in unconventional emergency events is confronted by insufficient information, limited time and the height of psychological pressure for decision makers. So, a scientific decision-making approach will play an important role in dealing with unconventional emergency events. The principle and idea of emergency plans-based decision making provides a new perspective to deal with unconventional emergency events. Thus, the evaluation of emergency plans is another important issue in emergency decision making.

This paper developed a new approach to evaluation of emergency plans for unconventional emergency events by combining the soft fuzzy rough set theory with the TOPSIS method. We first construct a soft fuzzy information system for the evaluation of emergency plans $(U, E, \tilde{F}^{-1})$. We then establish the optimal and the worst object plans based on the idea of TOPSIS. Finally, we give comprehensive evaluation results for choosing among several emergency plans by using soft fuzzy rough set theory. The model and method give a scientific and effective method of evaluating emergency plans and also can avoid the limitations of existing approaches (Zhang *et al.*, 2004; Luo *et al.*, 2008; Zhu *et al.*, 2011). So, this paper can be regarded as a valuable exploration of emergency decision making for unconventional emergency events by using rough set theory and soft set theory.

Generally speaking, there cannot be absolutely optimal decision making for management science problems in reality, and this applies as well to the evaluation of emergency plans. At the same time, many of these problems are essentially subjective in nature (e.g. affected by human understanding). Moreover, due to the differences in theoretical basis and processing methods, there is still no evaluation criterion that can strictly assess evaluation results based on theoretical tools. However, the choice of evaluation methods can play a key role in ranking results for emergency plans. The method of soft fuzzy rough set to evaluate emergency plans for unconventional emergency events in this paper is an initial attempt to apply the theory of soft fuzzy rough set to the management of unconventional emergency events.

In general, taking different approaches may have roughly the same consequence, or may result in different consequences under the same conditions. This depends mainly on the method of dealing with uncertainty of information. The method of soft fuzzy rough set to evaluate emergency plans proposed in this paper is an initial attempt to apply the theory of soft set theory and rough set theory for emergency decision making. Different evaluation methods can be constructed based on the above two theories in future research. Improving the evaluation model by combining other theories and methodologies can also be a worthwhile direction for study.

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