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ORIGINAL RESEARCH

A hybrid intelligent model for assessment of critical success factors in high-risk emergency system

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Abstract

High-risk emergency systems are emerging as a new generation technology to prevent disasters. Latest research points out that these systems could protect properties and lives in an efficient way. Limited to the sources, the feasible way to improve the performance of the system is to identify critical success factors (CSFs) and then optimize them. In this paper, a multi-criteria decision-making (MCDM) approach integrating Affinity Diagram, Decision Making Trial and Evaluation Laboratory (DEMATEL), fuzzy cognitive map (FCM) and Dempster–Shafer evidence theory (evidence theory) is proposed to identify critical success factors in high-risk emergency system. The DEMATEL and FCM are initially combined to tackle the decision-making problem in theory and practice. This model has ability to fuse technical, economic, political and social attributes. The proposed method is applied to select CSFs for Chongqing city.

Keywords DEMATEL · Fuzzy cognitive map · Dempster–Shafer evidence theory · Critical success factors · High-risk emergency system · Multi-criteria decision making

1 Introduction

Since the occurrence of nature disaster such as earthquakes, extreme climates and other environmental issues are becoming more relevant (Sheu 2007; Zappini et al. 2016), the demand for the high-risk emergency systems' performances is increasing proportional to population growth, industrialization and urbanization across the world (Zografos et al. 1998). Chongqing, as a central city located in southwest of China, has suffered continuously property losses recently. Thus, optimizing the performances of high-risk emergency systems in Chongqing city is necessary.

Until now, most existing studies focus on choosing one or two specific procedures of emergency systems to optimize (Li and Mahadevan 2016b). For example, Park used a training simulator of the nuclear power plant to analyze operators' performance under emergencies (Park and Jung 2007; Park et al. 2012). Cowing discussed tradeoffs between safety and productivity in critical engineering systems (Cowing et al. 2004; Yin and Deng 2018). Rouvroye and Bliek proposed an approach for comparing different safety analysis techniques in emergency management system and described the qualitative and quantitative results from comparison (Rouvroye and Bliek 2002).These methods can improve part performance instead of systematically improving overall performance of the system (Li and Mahadevan 2016a). Other researchers prefer a through upgrade for the emergency system (Belassi and Tukel 1996; Somers and Nelson 2001). However, it is not feasible in most situations due to the limitation of resources (Kang et al. 2018).

The study of critical success factors (CSFs) was developed by Bullen and Rockart (Bullen and Rockart 1981) as a method to enable decision makers to recognize their own information requirements so that information systems could be built to meet those requirements. Rockart defined CSFs as the necessary elements for achieving a goal. This concept has wide acceptance among scholars and practitioners. Some authors analysed some aspects of CSFs in other perspectives (Holland and Light 1999; Leidecker and Bruno 1984; Umble et al. 2003). In order to save resources, our main goal is to find CSFs in emergency system to improve the system efficiency.

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Since many related work addressing the specific activity of the emergency system has actually involved influencing factors, it is a feasible way to extract influencing factors from these literatures (Cavaliere et al. 2018; Loia et al. 2018). Based on an intensive literature review (Maio et al. 2017; Rathore et al. 2017), influencing factors have been managed to derive from summaries of factors in prior researches. However, limited to the source of the emergency system, it is unrealistic to improve all influencing factors simultaneously. For these reasons, A feasible way is to clarify the relationships among factors and to find out the most urgent and important factors because they have largest influence on the whole emergency system. If these factors are improved, the efficiency of emergency systems's performances can be greatly facilitated. Under these circumstances, the selection of critical success factors (CSFs) becomes crucial (Freund 1988; Zhang and Mahadevan 2017), also for precautionary investments in Chongqing. Establishment of emergency system in an efficient and economical way can be a viable option to eliminate the enormous losses and also to minimize the related negative environmental impacts. So decision makers can only focus on these CSFs. If we could identify CSFs accurately, we can pay main attention on these critical factors thus the whole performance of the system will be improved. In this situation, the cost will be minimized.

In the existing literature (Diaz-Valenzuela et al. 2016; Fujita et al. 2018), the definition of CSF are varied according to different occasions. As for high-risk emergency system, the components inside system interact with each other in a dynamic way. The relationships among factors are highly complex and each factor affects others in a nonlinear way. The CSFs in this paper is defined as the factors whose activation degree are high. Notice that the activation degree is dependent on influences exerted by other factors in high-risk emergency system, identifying CSFs is considered as a multi-criteria decision making (MCDM) problem in this paper. The challenge can be divided into two parts: (1) how to figure out relations among factors in high-risk emergency system and (2) how to quantify their activation degree caused by interactions from other factors.

MCDM is one of the popular methods to tackle with complicated problems that display high uncertainty, multiple perspectives, various interests and clashing objectives. Besides, MCDM methods are effective in weighting and selecting the most appropriate alternatives (Liu 2016; Tsai et al. 2017; Xiao et al. 2016; Zheng et al. 2017). Tseng et al. (2012), Wu (2012) and Zhou et al. (2011, 2017) adopted multi-criteria decision making methods to solve a complicated problem in different fields. Many mathematical theory and methods have been proposed to deal with MCDM problem.

As for the first questions, the domain experts will be invited to evaluate relations among different factors. Assessments of experts are imprecise due to lack of knowledge, environment randomness. So experts give their evaluations in the form of intuitionistic fuzzy sets instead of crisp numbers. To decrease subjectivity of experts, many experts will be invited to evaluate, the evidence theory is utilized to aggregate these opinions to obtain a comprehensive results. DEMATEL can effectively build the structure of a relationship map with clear interrelations among factors (Tsai et al. 2014, 2015). After infinite iterations, the total relationship matrix which contains a comprehensive relationships is presented. It can also be used to establish cause diagram in which causal relationships are visualized. So we put evaluations of experts into DEMATEL, relations among different factors are certain.

To quantify their activation degree caused by interactions from other factors. Fuzzy cognitive map is introduced. Fuzzy cognitive map (FCM) consists of neuro-fuzzy systems which are able to incorporate experts' knowledge (Christoforou and Andreou 2017; Papageorgiou et al. 2017; Salmeron and Palos-Sanchez 2017). FCM develops two major characteristics of traditional cognitive map (Salmeron et al. 2017). Firstly, the structure of FCM involves feedback that indicates the concept nodes may be affected by the changes of its connected nodes. Secondly, a FCM extends the causal relationships represented by a fuzzy value between -1 and $+1$ where the zero value indicates the absence of causality. From an artificial Intelligence view, FCMs are supervised learning neural systems (Mourhir et al. 2017; Salmeron et al. 2017). The system turns better at adapting itself and reaching a solution if more and more data are available to model the problem. In complex high-risk emergency system, the factors can be related to each other directly or indirectly. In such a situation, it becomes more challenging to describe the total relationships among the nodes in FCM because giving rise to linear activity with no dependence or feedback can cause problems that are more different than the ones in non-hierarchical systems. In the former literature, how to quantify the intensity and direction of connection among the nodes in a complex system is a question that limits the FCM to a wider application. In this study, connections relations can succeed from DEMATEL.

One of the aims of this research is to identify relevant potential CSFs that are crucial to improve whole performance of high-risk emergency system from a manager's perspective. The other is to propose an integrated framework that can be used to evaluate and rank CSFs for Chongqing city.

In this paper, the process of figuring out CSFs is considered as a multi-criteria decision making (MCDM) problems. The use of multi-criteria decision making techniques for emergency system optimization including identifying

CSFs, has since long attracted the interest of decision makers. Some similar but technically different solutions are presented (Chanyachatchawan et al. 2017; Yan et al. 2017). The main contributions of this paper are the development of an evaluation model from an manager perspective and the integration of DEMATEL and fuzzy cognitive methods in the framework of Dempster–Shafer evidence theory for an effective CSFs selection problem:

- Affinity Diagram is first introduced into the high-risk emergency system evaluations. It is recommended to use Affinity Diagram when factors or thoughts are uncertainty and needs to be organized which is highly matched with situations in high-risk emergency situations. Thus, Affinity Diagram can serve as an effective tools to decrease ignorance and uncertainty in experts' objective assessments and get a comparable precise evaluation.
- In literature, there are many studies which combines DEMATEL and other methods to tackle MCDM problems. In the same way, fuzzy cognitive map also have been applied into a wide range of areas due to its superiority to simulate the evolutionary process. Nevertheless, there is no study so far combined these two methods in theoretical nor in practice. This is the first time these two methods are combined to handle practical problem.
- Basic probability assignment is introduced to fuse opinions derived from different experts in a hybrid hierarchy structure. In the traditional MCDM processes, the divergences of ideas gathered from experts always hinder further process in the MCDM. Due to the superiority of Dempster–Shafer evidence combination rules, we could aggregate these evaluations to make decisions.
- There is no need for defuzzification of fuzzy numbers derived from expert's evaluations before utilizing DEMATEL method.

This paper has originality not only for its evaluation methodology, but also for its use on the real case, especially in those high-risk areas whose the occurrence of devastating disaster is frequent.

The rest of the paper is organized as follows. Section 2 sets some background of the issue. In Sect. 3, we present the basic methods that will be integrated to handle a real problem in the latter. In Sect. 5, we present our hybrid approach integrating Affinity Diagram, DEMATEL, fuzzy cognitive map and Dempster–Shafer evidence theory for Assessing critical success factors in high-risk emergency system. Section 5 presents an empirical application of the proposed approach. The verification and discussion of our method's rationality and superiority will be submitted in Sect. 6. In the last section, we present the conclusion of this paper.

2 Background

Since it is not a long time when CSFs have been proposed, there are few of literature related to it. Considering the relevance, two main streams of recent researches are reviewed here: one is focused on papers that discussed the high-risk emergency system and developments of managing them; and the other that developed and applied methodologies used in the MCDM. As it is seen, most of the article date back to 2017 and later on which shows in itself the potential for new work on the field of identifying CSFs in high-risk emergency systems. In this paper, the CSFs refers those factors which have a higher activation level in the emergency system when emergencies occur.

2.1 Literature of development of managing emergency system

The former researchers mainly focus on one or two specific activities, trying to improve certain procedures of emergency systems. For example, Park used a training simulator of the nuclear power plant to analyze operators' performance under emergencies (Park and Jung 2007; Park et al. 2012). Cowing discussed tradeoffs between safety and productivity in critical engineering systems (Cowing et al. 2004). Rouvroye and Bliek proposed an approach for comparing different safety analysis techniques in emergency management system and described the qualitative and quantitative results from comparison (Rouvroye and Bliek 2002). Tseng et al. (2012), Wu (2012) and Zhou et al. (2017, 2011) adopted multi-criteria decision making methods to solve this serious problem.iple.

The study of CSFs was developed Rockart (Bullen and Rockart 1981; Xu and Deng 2018) as a method to enable Chief Executive Officers to recognize their own information needs so that information systems could be built to meet those needs. Rockart defined CSFs as the needed elements for achieving a goal. This concept has wide acceptance among scholars and practitioners. Some authors analysed some aspects of CSFs in other perspectives. However, a few of them used a formal methodology (Zhou et al. 2016; Zheng and Deng 2018).

2.2 Literature review of related MCDM methods

MCDM is one of the popular methods to tackle with complicated problems that display high uncertainty, multiple perspectives, various interests and clashing objectives. Besides, MCDM methods are effective in weighting and selecting the most appropriate alternatives (Liu 2016; Tsai et al. 2017; Xiao et al. 2016; Zheng et al. 2017).

Fuzzy cognitive map (FCM) consists of neuro-fuzzy systems which are able to incorporate experts' knowledge (Christoforou and Andreou 2017; Papageorgiou et al. 2017; Salmeron and Palos-Sanchez 2017). FCM develops two major characteristics of traditional cognitive map (Salmeron et al. 2017). Firstly, the structure of FCM involves feedback that indicates the concept nodes may be affected by the changes of its connected nodes. Secondly, a FCM extends the causal relationships represented by a fuzzy value between −1 and +1 where the zero values indicate the absence of causality. From an artificial Intelligence view, FCMs are supervised learning neural systems (Mourhir et al. 2017; Salmeron et al. 2017). The system turns better at adapting itself and reaching a solution if more and more data are available to model the problem. In complex high-risk emergency system, the factors can be related to each other directly or indirectly (Deng et al. 2018; Bian et al. 2018). In such a situation, it becomes more challenging to describe the total relationships among the nodes in FCM because giving rise to linear activity with no dependence or feedback can cause problems that are more different than the ones in non-hierarchical systems. How to quantify the intensity and direction of connection among the nodes in a complex system is a question that limits the FCM to a wider application.

To deal with this issue, the DEMATEL method can be implemented. DEMATEL could effectively build the structure of relationships map with clear interrelations among factors (Tsai et al. 2014, 2015). It can also be used to establish cause diagram that are able to visualize the causal relationship. After infinite iterations, the total relationship matrix which contains a comprehensive relationships is presented. We use the DEMATEL to analyze the weight of arcs among the nodes in FCM, and using FCM's dynamic mechanism, a value that relates to its corresponding physical value will be obtained. These activation levels may be interpreted quantitatively or qualitatively. Once the FCM reaches equilibrium, the activation values provide the triggering or firing strength of those concepts for a given scenario. Specifically, triggering strength of each CSF is regarded as its activation degree in the emergency system when emergency situation occurs. A factor with larger activation degree will exerts more functions than those with relatively lower factors in the high-risk emergency system when dangerous situations occur. Thus these factors should be categorized as CSFs.

Basic probability assignments are introduced in order to decrease the uncertainty. Since multi-expert evaluations bear subjectivity and ignorance. The basic probability assignment could be used to fuse different opinions of experts thus obtain a comparable comprehensive results (Liu et al. 2017a, b; Su et al. 2015).

3 Preliminaries

3.1 Affinity diagram

An affinity diagram (which is also called KJ method invented by Kawakita Jiro) (Foster and Ganguly 2007; Zhang et al. 2018a) serves as an effective tool to generate groupings of data based on their natural relationship through analyzing verbal data gathered from survey, brainstorming or numerical simulations. Originally developed as a quality management tool, it is now applied in different domains for decision making and generating ideas. Ishikawa recommends using the Affinity Diagram when facts or thoughts are uncertain and need to be organized. The main procedures of affinity diagram is introduced as follows (Deng and Deng 2018; Liu et al. 2018):

(1) Identifying the problem and state it in a clear, concise and easily understandable way to the team members.
(2) Giving team members a supply of note cards and pen to ask them to write down issue related to problem. One idea should be written per card. Allow 10 mins for the writing activity.
(3) Place the written cards on a flat surface. Lay out the finished cards so that all members can see and have access to all cards.
(4) Let everyone on the team move the cards into groups with a similar theme without discussing. If you disagree with someone's placement of card, say nothing but move it silently.
(5) A consensus is reached when all cards are in groups and team members have stopped moving cards. When team members agree on the placement of cards, create header cards.
(6) Draw a finished Affinity Diagram and provide a working copy to all participants.

In this paper, we have used Affinity Diagram to generate some potential critical success factors (CSFs) for experts to evaluate and rank them. The team members participating in this exercise are from a organization named Reliability and Risk Engineering and Management in Vanderbilt University, USA, an office of disaster assistance of local government of Chongqing, China, and an emergency management company in Chongqing, China, respectively. These representatives should be chosen from different levels of hierarchy across all departments. There is no hard and fast rule on minimum or maximum number of participants. Ideally, the number should be good enough to represent all decision makers involved in urban emergency management activities.

3.2 DEMATEL method

The methodology of the Decision Making Trial and Evaluation Laboratory (DEMATEL) was originally developed by Battelle Memorial Association in Geneva (Fontela and Gabus 1976; Gabus and Fontela 1973), is an effective method for analysing direct and indirect relationship between components in the system in respect to its severity and type. Through the analysis of total relation of components by DEMATEL, a better understanding of the structural relationship and ideal way to solve complicate system problems can be obtained (Fekri et al. 2009; Tseng 2009; Tseng and Lin 2009; Tzeng et al. 2010). Essentially speaking, for a multitude number of factors which each other a lot, high-risk emergency management system can be regarded as a complex system. The steps of DEMATEL method can be divided into 4 Steps:

Step 1 Define the quality feature and establish measurement scale. Quality feature is a set of influential characteristics that impact the sophisticated system, which can be determined by expert evaluation, knowledge preference and simulation. Then establishing the measurement scale for the casual relationships and pairwise comparison among influential characteristics after defining the influential characteristics in the system. Four level 0, 1, 2, 3 are suggested "no impact", "low impact", "high impact", "extreme impact" respectively. In this step, factors and their directed relations are displayed by a weighted and directed graph.

Step 2 Extract the Direct Relation Matrix of influential factors. In this step, we transform the weighted direct graph to Direct Relation Matrix, for n influential factors F_1, $F_2, \cdots, F_n$, Direct Relation Matrix is denoted as $D = (d_{ij})_{n \times n}$ $(i, j = 1, 2, \ldots, n)$, where d_{ij} is the direct relation of F_i over F_j based on the measurement scale.

Step 3 Normalized Direct Relation Matrix. Normalized direct relations of factors are a mapping from d_{ij} to [0, 1], the normalized direct matrix N is calculated by:

$$N = \frac{D}{max_i(\sum_{j=1}^{n} d_{ij})} \quad (1)$$

Step 4 Calculate Total Relations Matrix. Total Relations Matrix contains direct and indirect relation among factors, the calculation is shown in the following:

$$T = N(I - N)^{-1} \quad (2)$$

where I is a $n \times n$ identity matrix. The value of $R + c$ and $R - C$ where C is the sum of columns and also R is the sum of rows in the matrix of T, a level of influence and a level of relationship are defined. The value $R_i - C_i$ indicates the importance of factors, and classified *ith* influential factor into the cause and effect category. $R_i + C_i$ is defined as the prominence, showing the impact of *ith* influential factors and its degree of being impacted. The DEMATEL map is shown in the Fig. 1.

3.3 Mathematical representation of fuzzy cognitive maps

Political scientist Robert Axelrod introduced cognitive map in the 1970's for representing social scientific knowledge (O'keefe and Nadel 1978). Fuzzy cognitive map (FCM), an extension of the cognitive map, is a causal description in order to model the behavior of the system (Kosko 1986; Papageorgiou et al. 2003). FCM is an interactive structure of concepts, each of which interacts with the rest showing the dynamics and different behavior of the system (Azadeh et al. 2014; Kang et al. 2012; Zhang et al. 2017a). Each concept is described by a number A_i that represents its value and it results from the transformation of the fuzzy real value of the system's variable, for which this concept stands, in the interval [0,1]. There are three types of causal interaction between concepts that represent the type of influence from concepts to the others (Kang and Deng 2018; Zheng and Deng 2017).

- The weights of the arcs between concepts C_i and C_j would be positive ($W_{ij} > 0$). It means that an increase in the value of concept C_i leads to the increase of the value of concept C_j, and a decrease in the value of concept C_i leads to the decrease of the value of the concept C_j.
- Or it could be a negative causality ($W_{ij} < 0$) which means that an increase in the value of concept C_i leads the decrease of the value of concept C_j and vice versa.
- In addition, it could be a zero causality ($W_{ij} = 0$) that means there is no relation between C_i and C_j.

The value A_i of concept C_i expresses a degree which is related to its corresponding physical value. At each interaction of the simulation, the value A_i of concept C_i is calculated by computing the effect of other concepts $C_j' s$ on

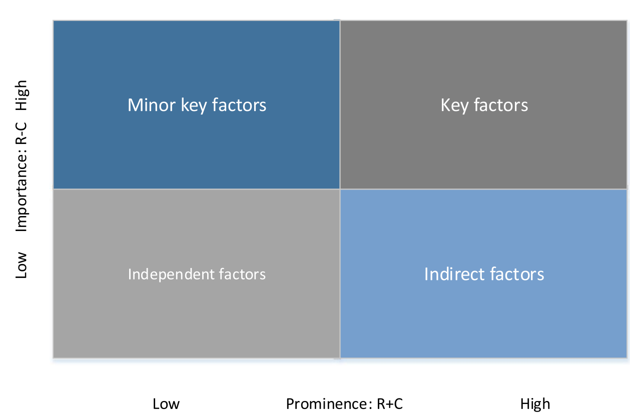

Fig. 1 DEMATEL map

the specific concept C_i. A typical formula suggested by Kosko for calculating the values of concepts of FCM is:

$$A_j^{(t+1)} = f\left(A_i^{(t)} + \sum_{j=1, j\neq i}^{n} W_{ji} A_j^{(t)}\right) \tag{3}$$

where $A_i^{(t+1)}$ is the value of the concept C_i at the step $t + 1$, $A_j^{(t)}$ is the value of the interconnected concept C_j at step t, W_{ji} is the weighted arc from C_j to C_i, and f is a threshold function to make sure the node concept value remains in the interval [0, 1] and could be the Sigmoid threshold function:

$$f = \frac{1}{1 + e^{-\lambda x}} \tag{4}$$

where $\lambda > 0$ determines the steepness of the continuous of function f. The Sigmoid function is usually used when the concept interval is [0, 1] and it is proved by Bueno and Salmero that this function offers significantly greater advantages than the other functions. For computational representation of FCM, a transition matrix is used. For the example in Fig. 2, it will look like:

$$\begin{pmatrix} 0 & w_{12} & 0 & 0 & 0 & w_{16} \\ 0 & 0 & w_{23} & 0 & 0 & 0 \\ 0 & 0 & 0 & w_{34} & 0 & 0 \\ 0 & 0 & w_{43} & 0 & 0 & 0 \\ 0 & 0 & w_{53} & w_{54} & 0 & w_{56} \\ 0 & 0 & 0 & 0 & w_{65} & 0 \end{pmatrix}$$

In this matrix, the number of rows and columns are equal to the number of concepts for factors. Non-zero elements in the matrix are equal to the number of vectors between nodes and indicate the relationship between i and j factors.At each time step, the values of concepts or nodes of fuzzy cognitive map would be calculated according to Eq. (3). The process stops when one of the following three states happen:

- Output concept values has been stabilized at a fixed value.
- Changes of the values have shown signs of cyclical.
- Chaotic state has appeared, that is, the concept value is uncertain and random.

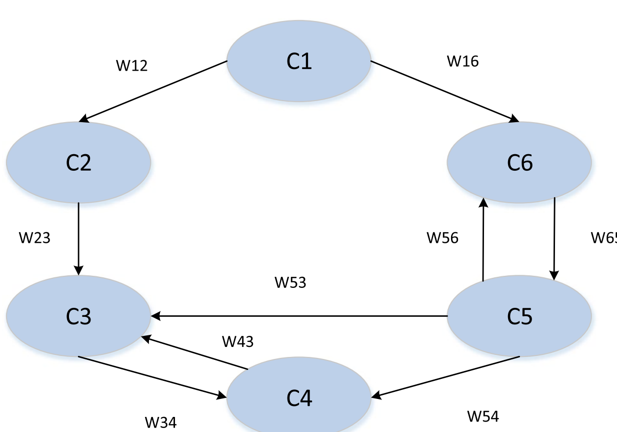

Fig. 2 Simple FCM

3.4 Dempster–Shafer evidence theory

Dempster–Shafer evidence theory (also known as evidence theory) (Dempster 1967, 2008; Shafer 1976) is regarded as an efficient tools to handle information in uncertain environment. The Dempster–Shafer evidence theory expresses "uncertain" by assigning the probability to subsets of the set composed of exclusive objects. The stronger the hypothesis, the bigger probability will be assigned to it, so it is the generalization of Bayes theory for it needs a weaker condition of Bayes theory. Dempster's combination rule is the most crucial tool of Dempster–Shafer evidence theory. Due to its superiority, it has been widely used in different areas (Jiang et al. 2017; Jiang and Zhan 2017; Kang et al. 2017; Zhang et al. 2017b).

Let Ω be a nonempty finite set and its elements are $\{\theta_1, \theta_2, \ldots, \theta_n\}$. Let 2^{Ω} be the set of all subsets of Ω, denoted $2^{\Omega} = \{\emptyset, \{\theta_1\}, \{\theta_2\}, \ldots \{\theta_n\}, \{\theta_1, \theta_2\}, \ldots, \{\theta_1, \theta_2 \ldots, \theta_n\}\}$.In Dempster–Shafer evidence theory (Shafer 1976), mathematically a basic probability assignment is a mapping: $2^{\Omega} \to [0, 1]$ that satisfies

$$\sum_{A \subseteq \Omega} m(A) = 1 \tag{5}$$

and

$$m(\emptyset) = 0 \tag{6}$$

If $m(A) > 0$, A is called a focal element, and the set of all focal elements is named a body of evidence. When multiple independent body of evidences are available, we can use the Dempster's combination rule to obtain the combined evidences as follows:

$$m(A) = \frac{\sum_{B,C \subseteq \Omega, B \bigcap C = A} m_1(B) m_2(C)}{1 - K} \tag{7}$$

where $K = \sum_{B \bigcap C = \emptyset} m_1(B) m_2(C)$ is a normalization constant, called conflict. The combination rule above makes sense only when $m_{\oplus}(\emptyset) \neq 1$, otherwise, the evidences are totally conflict indicting that we can not use combining rules.

3.5 Intuitionistic fuzzy set

Let $X = \{x_1, x_2, \dots, x_n\}$ be a finite universal set. An intuitionistic fuzzy set (IFS) (Atanassov 1986) A in X is an object having the following form:

$$A = \{< x_j, \mu_A(x_j), v_A(x_j) > | x_j \in X\}$$

where the functions

$\mu_A : X \longmapsto [0, 1]$

$x_j \in X \to \mu_A(x_j) \in [0, 1]$

and

$v_A : X \longmapsto [0, 1]$

$x_j \in X \to v_A(x_j) \in [0, 1]$

define the degree of membership and degree of non-membership of the element $x_j \in X$ to the set $A \subseteq X$, respectively, and for every $x_j \in X$, $0 \le \mu_A(x_j) + v_A(x_j) \le 1$. We call $\pi_A(x_j) = 1 - \mu_A(x_j) - v_A(x_j)$ the intuitionistic index of the element x_j in the set A. It is the degree of indeterminancy membership of the element $x_j \in X$ to the set A. It is obvious that for every $x_j \in X, 0 \le \pi_A(x_j) \le 1$. Following the conceptions of IFS, some concepts and arithmetic operations of intuitionistic fuzzy numbers, shortly, IFNs. An IFN a is defined as an ordered pair (μ_a, v_a) satisfying the following conditions:

$$\mu_a \in [0, 1], \quad v_a \in [0, 1], \quad \mu_a + v_a \le 1$$

IFNs have been widely applied in MCDM problems (Fei et al. 2017; Mo and Deng 2016; Zhang et al. 2018b), in this paper, the evaluations given by experts is presented in the form of IFNs.

4 The proposed method

Different methods can be used to build FCMs. These are normally constructed through multi-step processes, where experts in the domain develop their mental models. In doing so, we propose to combine augmented FCM with DEMATEL. FCM has already been previously hybridized with diverse techniques for supporting decision-making methods. The driving forces for developing hybrid approaches lies in Li et al. (2002): A. Avoiding the weakness of individual techniques and integrating their strengthens; or B. Getting multiplicity of application tasks when single technique cannot deal with different sub-problems of given task. Table 1 provides a comparison list of hybrid approaches based on FCM and their reasons. Connecting the driving force B, FCM allows to calculate local or global weights to be used in TOPSIS, AHP, ANP to assess alternatives (Nacházel 2015; Yu and Tzeng 2006). FCM thus overcomes the problem of interdependence among criteria, as well as problem of hard questions derived from pairwise comparison. On the other side, AHP allows to determine the initial state vector simulated in the FCM inference process by considering multiple criteria (Biloslavo and Dolinšek 2010). Primitive Cognitive Network Process measures the initial values of experts to be further process in FCM. However, the question of transforming linguistic evaluations of feedback between FCM variables into quantitative evaluations in environment where the factors are interacting with each others direct or indirectly has not been yet tackled. The defuzzification is often carried out by using the centroid method, the max aggregation method or mamdani inference mechanism (Mago et al. 2012). To bridge this gap, we utilize Dempster–Shafer evidence theory to aggregate experts evaluation. DEMATEL is used to quantify arcs' weights to be further processed in FCM, which strengthens robustness of the final FCM model. Here, we propose a new combination of DEMATEL and FCM (DEMATEL-FCM). The proposed DEMATEL-FCM model for identifying critical success factors(CSFs) consists of following 5 Steps:

1. Selection of potential CSFs using Affinity Diagram.
2. Turn the linguistic evaluation into IFNs matrixes to express the relationships among the factors. The IFNs can be transferred into basic probability assignments and then use Dempster–Shafer evidence combination rules to aggregate them.
3. Apply DEMATEL method to calculate the total relationships among the factors. In our approach, DEMATEL is utilized in two aspects, The relationship among the factors will be visualized in DEMATEL map.
4. Using FCM dynamic mechanism to obtain the activation degree while the arcs' weights are obtained from the results of Step 3.
5. Identify the CSFs in comprehensive consideration of the corresponding results of each factor in the FCM which represents its physical value and the degree of activation. Those factors which have larger values will be classified as CSFs since it will be reach its maximum normalized value in the system.

The Steps are presented in details as follows:

Step 1: Define the potential CSFs of the emergency system through the procedures of Affinity Diagram procedures introduced in Sect. 3. Some potential CSFs will be listed out. These factors have the largest probability to be the CSF according to expert' experience, knowledge and other methods, the following procedure is to rank them.

Step 2: The experts evaluation will be submitted in Step 2. Multiple evaluations from experts are required to decrease the uncertainty, experts can evaluate the relationship between factors.

Step 2.1: Multiple experts are requested to evaluate the direct relations between each pair of influential

Table 1 List of hybrid approaches based on FCM

Article	Objective	Combined techniques	Driving forces	Explanation
Yu and Tzeng (2006)	Numerical examples	ANP and FCM	A	FCM estimates global weight vector of ANP
Biloslavo and Dolinšek (2010)	Impact of organizational and technological changes on climate-related issues	Delphi, AHP and FCM	A	Delphi techniques identify factors, AHP computes the initial state vector then simulated in the FCM inference process
Shiau and Liu (2013)	Evaluate transport sustainability strategies	AHP and FCM	B	AHP ranks key sustainable indicators. The 10 first are used in the FCM to build causal-relationships between them
Asadi et al. (2014)	Determine automated feature model configuration	AHP, FCM and HTN	B	AHP calculates local weights; meanwhile FCM estimates global weights. HTN finds the optimal feature model configuration
Zhou and Yuen (2014)	Measures the factors on box office sales	PCNP and FCM	A	PCNP quantifies the weights of factors to construct a concept in FCM. FCM simulates the influences on each other
Ahmadi et al. (2015)	Managing readiness relevant activities in implementing an ERP system	FAHP, FCM and DEMATEL	B	FAHP computes the readiness contribution weight of activities. FCM determines how these activities interact on each other. The multiplication of both FAHP and FCM inference's results determines the overall REP readiness assessment by using static FCM model
Azadeh et al. (2015)	Evaluating and optimizing the leanness degree of organization	FDEA, FCM, DEMATEL and AHP	B	FCM and FDEA separately quantify firms leanness and rank them. DEMATEL evaluates impact degree of leanness factors on each other, and subsequently AHP and DEA rank them
Baykasoğlu and Gölcük (2015)	Prioritize strategies for transforming higher education systems	Fuzzy TOPSIS and FCM	A	FCM estimates the attribute weights to be used in TOPSIS to rank alternatives
Nacházel (2015)	Decision-making in artificial life	AHP and FCM	B	FCM estimates the weight of criteria used to determine which activity should individual choose with AHP
Kang et al. (2016)	Evaluation of the oil-spill emergency response capability	AHP and FCM	B	FCM and AHP determine the weights in the first and second level of the distribution model, respectively
López et al. (2017)	Case studies	AHP and FCM	B	FCM and AHP are utilized to support offshore outsourcing location decision-making considering supply chain resilience

factors in high-risk emergency system, the results will be presented as IFNs matrixes. Suppose s experts are invited to make judgements on the direct relations of m influential factors and corresponding IFN matrixes are denoted as $M_k = [(y^k_{ij}, n^k_{ij})]_{m\times m}$ $(i,j = 1,2,\dots,m$ *and* $k = 1,2,\dots,s)$, where y^k_{ij} indicates the *kth* expert evaluations o direct relation of i to the factor j from positive side while n_{ij} indicates the *kth* expert evaluations on direct relation of factor i to j from negative side.

Step 2.2: After gathering the IFN matrix from expert evaluations. We would transform IFNs matrix to basic probability assignment matrix, then Dempster–Shafer evidence theory is used to fuse group opinions according to the Dempster–Shafer evidence combination rules. Suppose s experts have made the judgements on m influential factors and corresponding IFN matrixes are $M_1, M_2, \dots, M_s$, according to Eq. (7), the fused IFN matrix could be required as $M = [(y_{ij}, n_{ij}, \theta)]_{m\times m} (i,j = 1,2,\dots,m)$, where y_{ij} indicates the fused experts evaluations on direct relation of factor i to factor j from positive side while n_{ij} means the fused experts evaluations on direct relation of factor i to j from negative side and θ indicates the uncertainty of experts.

Step 3: Construct the direct-relation matrix using DEMATEL. Firstly, turn the fused IFN matrix in to fused direct relation matrix from positive side and negative side. As for the fused IFN matrix $M = [(y_{ij}, n_{ij}, \theta)]_{m\times m}$ $(i,j = 1,2,\dots,m)$, the positive direct relation matrix $M_y = [(y_{ij})]_{m\times m}$ $(i,j = 1,2,\dots m)$ and $M_n = [(1 - n_{ij})]_{m\times m}$ $(i,j = 1,2,\dots m)$ is the direction matrix from negative side.

Step 3.1: Normalize the direct-relation matrix: The direct relation matrix M_y and M_n are used to calculate the normalized direct relation matrix using the formula (1).

Step 3.2: Calculate the total relation matrix from positive and negative perspective. Once the normalized matrix M_y and M_n are obtained, the formula (2) is implemented to compute the total relation matrix T.

Step 3.3: To make a visualized relations among the factors, we calculate the dispatcher and receiver groups. The dispatcher is calculated from $D - R$ which has positive values and higher influences on other factors. They are assumed to exhibit higher higher priority and are called dispatcher groups, where R is the sum of the columns and D is the sum of rows in the matrix T. The other values with negative values of $D - R$ receiving more influence from another are considered to have a lower priority and are called receiver groupers. The value $D + R$ here shows the relation degree between each factor with others. Those factors are exhibiting more relationship with other and those having lower $D + R$ have less relationship with others. The concrete algorithm is displayed in the Table 2.

Table 2 Algorithm transformation of DRM to TRM in DEMATEL

```
Algorithm1:   Transformation of DRM to TRM in DEMATEL
Input: A DRM   D=(d_ij)_{n×n}(i,j = 1,2,···,n))   in DEMATEL;
Output: A TRM   T=(t_ij)_{n×n}(i,j = 1,2,···,n))   of   D   in DEMATEL;
Initial E=eye(n);
for all i do
    SR(i,1) = ∑_{j=1}^{n} d_ij;   %Calculate the sum of each row of D
end for
maxsr = max(SR);   % Find the maximum sum of each row of D
N = D/maxsr;   % Normalize the DRM D
T = (I − N)/N;   %Calculate the TRM T where T = N(I − E)^{-1}
```

Step 4: Constructing FCM, the nodes are CSFs, and the arcs as well as their weights are derived from DEMATEL in positive and negative perspective. Since FCM is a dynamic system, three different states will be reached after several iterations introduced in Eq. (3) and the procedure is described in Algorithm 2 in Table 3 in detail. Notice that the nodes whose physical values are less than 0.5 are assumed exert no influences on the emergency system so they are not CSFs.

Step 5: Those nodes whose corresponding physical values are higher then other are identified as the CSFs in comprehensive consideration since they will reach a maximum of normalized value, which means they are more active in the high-risk emergency system when the emergency situations occur. A general view of our proposed hybrid evaluation method is shown in Fig. 3.

5 A case to study

Based on the hybrid method integrating DEMATEL, FCM, Affinity Diagram, Dempster–Shafer evidence theory, an illustration of identifying CSFs in high-risk emergency system in Chongqing is presented in this section. The illustration is on the basis of the following assumptions.

- There are lots of influential factors in the whole system. However, our experts select few factors among them using their knowledge base and experience and we will discuss and rank these factors.

Table 3 The detail algorithm of FCM dynamic procedure

Algorithm2: The convergent procedure of state vector of FCMs

```
Input: The initial state vector of nodes, X_i = [A_1, A_2, ..., A_n]; the matrix of edge weight W_{n×n}
Output: The equilibrium state vector of nodes, X_e = [A_1, A_2, ..., A_n];
Temp=[]=X_i;
While not satisfy the condition do
  X_i = Temp;
  for j = 1; j ≤ n; do
    sum=0;
    for j = 1; j ≤ n; do
      if i ≠ j then then
        a = X_i(i) * W(i, j);
        sum=sum+a;
      end;
    end;
    sum = sum + X_i(j);
    Temp(j) = function(sum);
    if Temp(j) ≤ 0.5 then
      Temp(j) = 0 ;
    end ;
  end ;
  X_e = Temp;
end ;
return X_e;
```

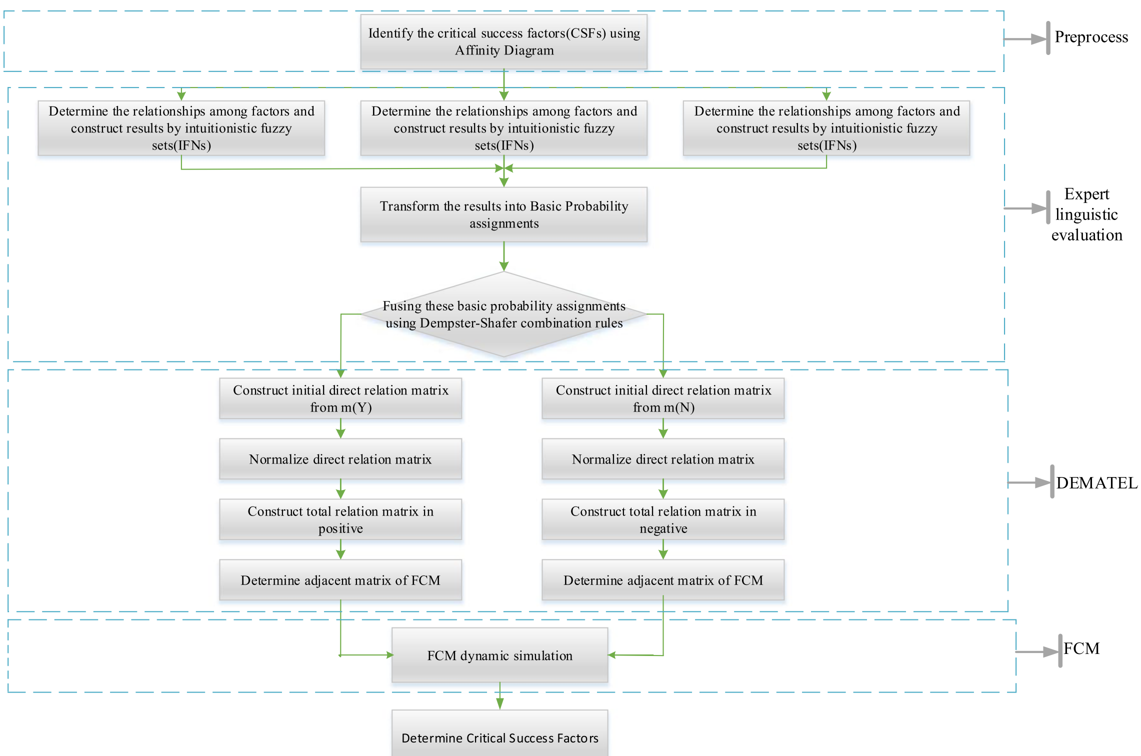

Fig. 3 Flowchart of the proposed DEMATEL-FCM model

- The experts are authority and professional in risk analysis and emergency management.

With the detailed procedures proposed in the last section, the CSFs are identified step by step as below.

Step 1: First of all, ten potential influential factors in emergency system are figured out by implementing the Affinity Diagram. The 10 potential CSFs are listed in Table 4.

Step 2.1: Three authorities in the emergency evaluation area are invited to evaluate the direct relation of factors and the results are displayed in the form of IFNs in Tables 5, 6 and 7. For example, IFN number (0.3, 0.5) in Table 5 indicates the membership degree of direct relation of factor F1 to F6 is 0.3 while the non-membership degree is 0.5.

Step 2.2: After gathering IFNs matrix we will transform it to basic probability assignment matrix, still taking (0.3, 0.5) as

Table 4 Factors influencing emergency management

Factors	Description
F1	Well-planned emergency relief supply system
F2	Reasonable organizational structure and clear awareness of responsibilities
F3	Applicable emergency response plan and regulations
F4	Education campaign on disaster prevention and response
F5	Regular organization of simulated disaster exercise
F6	Government unity of leadership to plan and coordinate as a whole
F7	Timely and accurate relief needs assessment
F8	The security of relief aids during distribution and transportation
F9	Clear procedure of reporting and submitting information
F10	Application of modern logistics technology

Table 5 The initial direct relation matrix of the first expert

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	(0,0)	(0.04,0.9)	(0.1,0.9)	(0.2,0.7)	(0.2,0.7)	(0.3,0.5)	(0.4,0.5)	(0.8,0.1)	(0.2,0.6)	(0.4,0.5)
F2	(0.7,0.2)	(0,0)	(0.5,0.4)	(0.4,0.4)	(0.6,0.2)	(0.5,0.4)	(0.6,0.3)	(0.5,0.3)	(0.7,0.1)	(0.3,0.6)
F3	(0.5,0.4)	(0.2,0.7)	(0,0)	(0.2,0.7)	(0.3,0.6)	(0.2,0.71)	(0.2,0.7)	(0.4,0.4)	(0.4,0.5)	(0.1,0.8)
F4	(0.15,0.7)	(0.2,0.7)	(0.1,0.9)	(0,0)	(0.2,0.6)	(0.1,0.9)	(0.1,0.8)	(0.2,0.6)	(0.2,0.6)	(0.1,0.7)
F5	(0.3,0.6)	(0.5,0.4)	(0.6,0.2)	(0.5,0.4)	(0,0)	(0.2,0.7)	(0.2,0.7)	(0.3,0.6)	(0.5,0.3)	(0.4,0.5)
F6	(0.5,0.4)	(0.5,0.4)	(0.3,0.6)	(0.25,0.7)	(0.5,0.4)	(0,0)	(0.4,0.5)	(0.4,0.5)	(0.38,0.55)	(0.4,0.5)
F7	(0.51,0.4)	(0.12,0.8)	(0.3,0.55)	(0.1,0.9)	(0.1,0.9)	(0.2,0.7)	(0,0)	(0.74,0.2)	(0.1,0.6)	(0.2,0.7)
F8	(0.6,0.3)	(0.3,0.5)	(0.2,0.7)	(0.1,0.9)	(0.1,0.9)	(0.4,0.5)	(0.6,0.1)	(0,0)	(0.1,0.5)	(0.4,0.3)
F9	(0.3,0.6)	(0.6,0.1)	(0.3,0.4)	(0.1,0.8)	(0.2,0.7)	(0.4,0.4)	(0.6,0.2)	(0.65,0.2)	(0,0)	(0.4,0.4)
F10	(0.5,0.4)	(0.3,0.6)	(0.4,0.5)	(0.1,0.7)	(0.3,0.5)	(0.3,0.6)	(0.3,0.6)	(0.7,0.1)	(0.4,0.4)	(0,0)

Table 6 The initial direct relation matrix of the second expert

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	(0,0)	(0.02,0.9)	(0.09,0.9)	(0.12,0.8)	(0.4,0.6)	(0.28,0.62)	(0.6,0.29)	(0.95,0.001)	(0.3,0.6)	(0.2,0.65)
F2	(0.5,0.35)	(0,0)	(0.58,0.3)	(0.33,0.56)	(0.45,0.44)	(0.72,0.2)	(0.65,0.23)	(0.42,0.43)	(0.6,0.34)	(0.2,0.67)
F3	(0.32,0.58)	(0.18,0.62)	(0,0)	(0.12,0.7)	(0.4,0.5)	(0.31,0.65)	(0.1,0.86)	(0.52,0.41)	(0.52,0.31)	(0.23,0.65)
F4	(0.2,0.7)	(0.15,0.75)	(0.03,0.9)	(0,0)	(0.28,0.6)	(0.11,0.8)	(0.1,0.85)	(0.3,0.55)	(0.1,0.8)	(0.24,0.7)
F5	(0.36,0.6)	(0.2,0.7)	(0.7,0.2)	(0.4,0.6)	(0,0)	(0.2,0.7)	(0.18,0.7)	(0.3,0.6)	(0.5,0.36)	(0.1,0.6)
F6	(0.5,0.4)	(0.5,0.4)	(0.3,0.6)	(0.38,0.5)	(0.5,0.4)	(0,0)	(0.4,0.5)	(0.34,0.54)	(0.4,0.5)	(0.5,0.45)
F7	(0.5,0.3)	(0.1,0.7)	(0.28,0.6)	(0.01,0.94)	(0.1,0.85)	(0.1,0.8)	(0,0)	(0.6,0.1)	(0.1,0.8)	(0.23,0.6)
F8	(0.65,0.2)	(0.3,0.6)	(0.25,0.6)	(0.02,0.9)	(0.1,0.9)	(0.4,0.5)	(0.5,0.3)	(0,0)	(0.2,0.5)	(0.3,0.4)
F9	(0.35,0.55)	(0.6,0.2)	(0.4,0.3)	(0.02,0.9)	(0.15,0.55)	(0.3,0.5)	(0.8,0.1)	(0.63,0.2)	(0,0)	(0.3,0.6)
F10	(0.5,0.4)	(0.3,0.5)	(0.4,0.5)	(0.03,0.8)	(0.3,0.6)	(0.5,0.4)	(0.4,0.5)	(0.8,0.2)	(0.4,0.3)	(0,0)

an example, this IFN can be converted into basic probability assignment as follows:

$$m(Y) = 0.3, \quad m(N) = 0.5, \quad m(\theta) = 0.2$$

where $m(Y) = 0.3$ expresses the degree of direct relation of factor $F1$ to $F6$ is 0.3, and $m(N)$ indicates the degree of no direct relation between $F1$ to $F6$ is 0.5 and $m(\theta) = 0.2$ describe uncertainty. By doing so, the basic probability assignment matrix can be obtained. Then we aggregate these three matrix and obtain a fused matrix whose element are $m(Y), m(N), m(\theta)$ and we place it into three tables (Tables 8, 9 and 10).

Step 3 Based on Step 2, we can get the direction relation matrix from positive and negative. Limited to the space, we don't list them in the paper. then using DEMATEL method, we will acquire comprehensive total relation matrix in both positive and negative which is shown in Tables 11 and 12. According to the results obtained, it is seen that there is

Table 7 The initial direct relation matrix of the third expert

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	(0,0)	(0.06,0.9)	(0.065,0.92)	(0.02,0.9)	(0.36,0.7)	(0.21,0.75)	(0.54,0.38)	(0.82,0.1)	(0.1,0.75)	(0.3,0.59)
F2	(0.62,0.2)	(0,0)	(0.3,0.64)	(0.41,0.5)	(0.52,0.32)	(0.63,0.28)	(0.45,0.4)	(0.3,0.55)	(0.5,0.4)	(0.26,0.6)
F3	(0.34,0.6)	(0.25,0.68)	(0,0)	(0.11,0.81)	(0.35,0.57)	(0.13,0.6)	(0.25,0.7)	(0.51,0.4)	(0.23,0.56)	(0.29,0.58)
F4	(0.25,0.6)	(0.28,0.6)	(0.06,0.8)	(0,0)	(0.22,0.7)	(0.05,0.8)	(0.2,0.65)	(0.3,0.66)	(0.1,0.7)	(0.16,0.75)
F5	(0.37,0.52)	(0.4,0.45)	(0.62,0.3)	(0.2,0.72)	(0,0)	(0.16,0.8)	(0.2,0.6)	(0.38,0.5)	(0.4,0.5)	(0.35,0.55)
F6	(0.53,0.4)	(0.55,0.4)	(0.25,0.6)	(0.3,0.6)	(0.4,0.5)	(0,0)	(0.4,0.5)	(0.45,0.45)	(0.38,0.5)	(0.4,0.5)
F7	(0.46,0.42)	(0.15,0.8)	(0.44,0.5)	(0.01,0.9)	(0.15,0.7)	(0.21,0.7)	(0,0)	(0.7,0.1)	(0.1,0.9)	(0.1,0.8)
F8	(0.55,0.4)	(0.3,0.6)	(0.25,0.6)	(0.06,0.8)	(0.05,0.8)	(0.3,0.5)	(0.5,0.3)	(0,0)	(0.1,0.8)	(0.5,0.4)
F9	(0.3,0.6)	(0.6,0.4)	(0.4,0.6)	(0.1,0.7)	(0.2,0.7)	(0.4,0.4)	(0.7,0.1)	(0.5,0.3)	(0,0)	(0.6,0.2)
F10	(0.6,0.33)	(0.3,0.5)	(0.3,0.6)	(0.07,0.8)	(0.31,0.5)	(0.4,0.5)	(0.46,0.5)	(0.75,0.16)	(0.5,0.43)	(0,0)

Table 8 The value of m(Y) for the fusion result of three experts

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0.000	0.010	0.0077	0.0922	0.1050	0.6651	0.9978	0.0684	0.1726
F2	0.8788	0	0.5059	0.3541	0.7404	0.8694	0.8068	0.4630	0.8555	0.1095
F3	0.3087	0.0666	0	0.0244	0.2379	0.0762	0.0224	0.5994	0.4006	0.0536
F4	0.0621	0.0556	0.0024	0	0.0930	0.0048	0.0148	0.1327	0.0299	0.0359
F5	0.2129	0.2889	0.9073	0.2188	0	0.0317	0.0602	0.2060	0.5959	0.1986
F6	0.6469	0.6570	0.1454	0.1543	0.5441	0	0.3647	0.3652	0.3262	0.4322
F7	0.6460	0.0164	0.2396	0.0007	0.0065	0.0292	0	0.9538	0.0109	0.0387
F8	0.8418	0.1853	0.0923	0.0024	0.0026	0.3280	0.8110	0	0.0554	0.5364
F9	0.1823	0.8710	0.4000	0.0055	0.0645	0.4057	0.9641	0.8725	0	0.5281
F10	0.7063	0.2187	0.2821	0.0092	0.2215	0.3617	0.3052	0.9758	0.5665	0

Table 9 The value of m(N) for the fusion result of three experts

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0.9989	0.9990	0.9914	0.9096	0.8932	0.3323	0.0017	0.9261	0.8233
F2	0.1155	0	0.4917	0.6405	0.2510	0.1288	0.1887	0.5251	0.1416	0.8865
F3	0.6895	0.9308	0	0.9734	0.7599	0.9219	0.9772	0.3970	0.5897	0.9435
F4	0.9338	0.9421	0.9976	0	0.9031	0.9949	0.9840	0.8646	0.9641	0.9623
F5	0.7858	0.7067	0.0894	0.7813	0	0.9676	0.9355	0.7909	0.3966	0.7945
F6	0.3510	0.3415	0.8512	0.8441	0.4529	0	0.6324	0.6313	0.6713	0.5663
F7	0.3482	0.9825	0.7575	0.9993	0.9935	0.9693	0	0.0409	0.9892	0.9584
F8	0.1563	0.8100	0.9032	0.9976	0.9974	0.6667	0.1664	0	0.9271	0.4437
F9	0.8152	0.1290	0.6000	0.9925	0.9304	0.5755	0.0299	0.1175	0	0.4607
F10	0.2916	0.7722	0.7151	0.9854	0.7697	0.6353	0.6936	0.0242	0.4234	0

Table 10 The value of m(θ) for the fusion result of three experts

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0.0002	0	0.0009	0.0009	0.0018	0.0027	0.0005	0.0055	0.0041
F2	0.0057	0	0.0024	0.0054	0.0087	0.0018	0.0045	0.0119	0.0029	0.0039
F3	0.0018	0.0027	0	0.0022	0.0022	0.0019	0.0004	0.0036	0.0096	0.0030
F4	0.0041	0.0023	0	0	0.0039	0.0003	0.0011	0.0027	0.0060	0.0018
F5	0.0012	0.0044	0.0033	0	0	0.0007	0.0043	0.0031	0.0075	0.0068
F6	0.0021	0.0015	0.0035	0.0016	0.0030	0	0.0029	0.0035	0.0025	0.0016
F7	0.0058	0.0012	0.0029	0	0	0.0015	0	0.0053	0	0.0029
F8	0.0019	0.0048	0.0045	0	0	0.0053	0.0227	0	0.0175	0.0199
F9	0.0026	0	0	0.0020	0.0052	0.0189	0.0060	0.0100	0	0.0112
F10	0.0021	0.0091	0.0028	0.0054	0.0087	0.0030	0.0012	0	0.0101	0

Table 11 The comprehensive total relation matrix from positive side

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.0805	0.0246	0.0264	0.0059	0.0303	0.0472	0.1819	0.2506	0.0346	0.0675
F2	0.3160	0.0899	0.1751	0.0844	0.1878	0.2221	0.3016	0.2960	0.2316	0.1097
F3	0.1154	0.0438	0.0301	0.0112	0.0592	0.0442	0.0727	0.1760	0.0976	0.0466
F4	0.0263	0.0162	0.0087	0.0022	0.0212	0.0084	0.0178	0.0398	0.0134	0.0143
F5	0.1199	0.0945	0.1994	0.0493	0.0338	0.0509	0.0954	0.1472	0.1534	0.0778
F6	0.2360	0.1673	0.0934	0.0468	0.1417	0.0643	0.1849	0.2171	0.1288	0.1335
F7	0.1755	0.0211	0.0584	0.0036	0.0145	0.0311	0.0065	0.2348	0.0215	0.0413
F8	0.2405	0.0649	0.0521	0.0093	0.0309	0.0954	0.2251	0.1311	0.0507	0.1328
F9	0.2026	0.2101	0.1390	0.0226	0.0715	0.1490	0.3094	0.3317	0.0815	0.1622
F10	0.2472	0.0964	0.1026	0.0154	0.0779	0.1214	0.1833	0.3163	0.1526	0.0689

Table 12 The comprehensive total relation matrix from negative side

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.2727	0.0299	0.0318	0.0074	0.0363	0.0566	0.2150	0.2944	0.0436	0.0814
F2	0.3725	0.2843	0.2065	0.1003	0.2224	0.2620	0.3565	0.3510	0.2747	0.1322
F3	0.1366	0.0528	0.2138	0.0139	0.0704	0.0534	0.0873	0.2083	0.1178	0.0568
F4	0.0325	0.0200	0.0107	0.1804	0.0260	0.0106	0.0223	0.0483	0.0177	0.0178
F5	0.1421	0.1125	0.2345	0.0581	0.2182	0.0613	0.1147	0.1750	0.1829	0.0943
F6	0.2772	0.1968	0.1107	0.0555	0.1670	0.2540	0.2186	0.2560	0.1534	0.1584
F7	0.2074	0.0260	0.0697	0.0045	0.0176	0.0377	0.2576	0.2771	0.0285	0.0507
F8	0.2847	0.0790	0.0638	0.0115	0.0376	0.1147	0.2712	0.3353	0.0659	0.1617
F9	0.2400	0.2476	0.1642	0.0277	0.0862	0.1798	0.3664	0.3930	0.2766	0.1952
F10	0.2912	0.1162	0.1222	0.0198	0.0941	0.1445	0.2177	0.3724	0.1837	0.2610

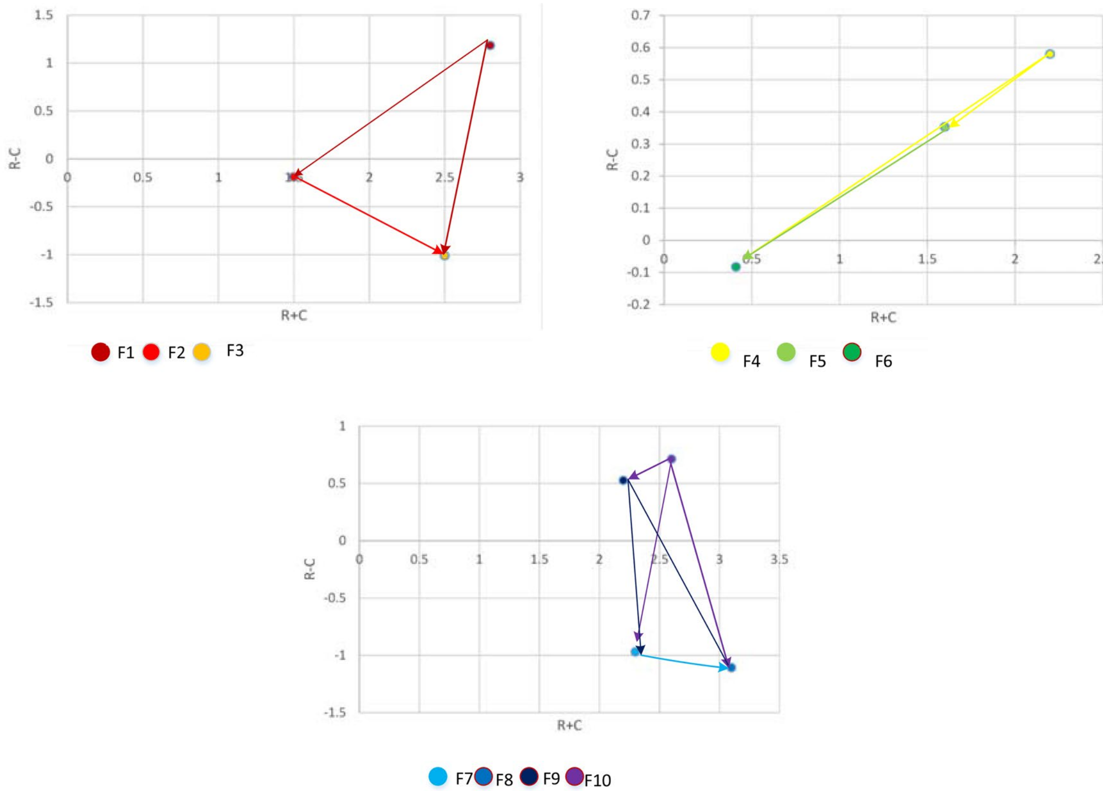

Fig. 4 The impact-diagraph map of the total relations for CSFs

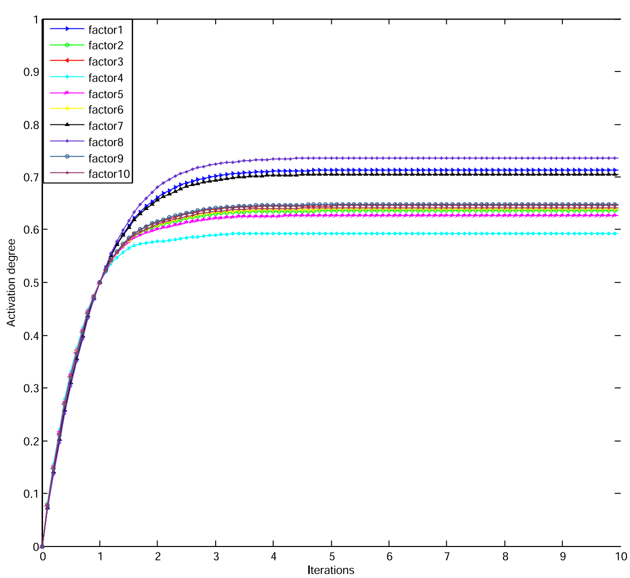

Fig. 5 Results of DEMATEL-FCM simulations from positive perspective

strong inner dependence among emergency CSFs. It can seen from the converging $D_i + R_i$ values, which reveals the degree of relation and prove a strong inner dependence. The following CSFs are calculated in the same way and exhibited in Fig. 4.

Step 4 Having the total relationships among CSFs, we could construct the FCM and use its dynamic mechanism to quantify the importance of each CSF when dangerous occurs. The activation value of each factor represents its importance. According to this, we rank them in decedent order. The procedure of evolutionary of FCM in positive and negative are shown in Figs. 5 and 6. It can be observed that FCM reaches equilibrium after 6 iterations, the activation levels are transformed bach to the corresponding values. These activation levels may be interpreted quantitatively and qualitatively. For example, factor 8 is 73.65% of its maximum normalized value in positive perspective and it is the most important factor in high-risk emergency system.And whole procedure can be interpreted as a process of inference. The detailed equilibrium values of each factors in positive and negative are listed in Tables 13 and 14.

Step 5: Those nodes whose corresponding physical values are higher then other are identified as the CSFs in comprehensive consideration since they will reach a maximum of normalized value, which means they are more active in the high-risk emergency system when the emergency situations occur. The ranks of CSFs are showed in Fig. 7.

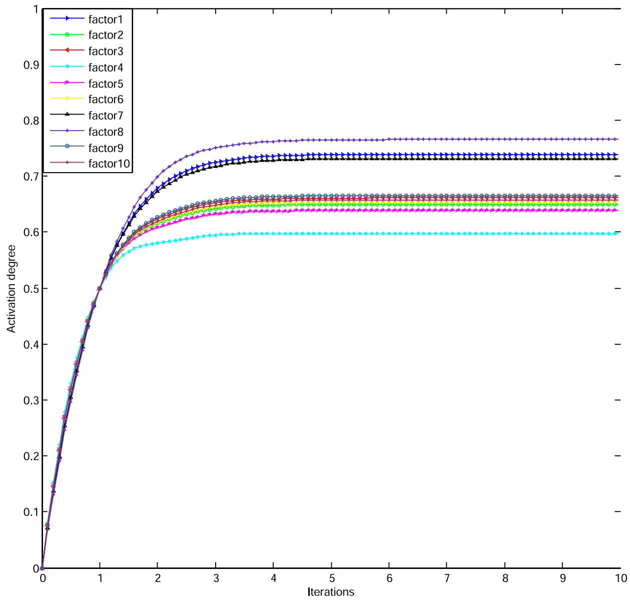

Fig. 6 Results of DEMATEL-FCM simulations from negative perspective

6 Discussion and comparison with other methods

The results in last section suggests that in high-risk emergency environment, F8 (The security of relief aids during distribution and transportation) > F1 (Well-planned emergency relief supply system) > F7 (Timely and accurate relief needs assessment) > F9 (Clear procedure of reporting and submitting information) > F3 (Applicable emergency response plan and regulations) > F10 (Application of modern logistics technology) > F6 (Government unity of leadership to plan and coordinate as a whole) > F2 (Reasonable organizational structure and clear awareness of responsibilities) > F5 (Regular organization of simulated disaster exercise) > F4 (Education campaign on disaster prevention and response) are identified as CSFs. In this section, we make further analysis on the superiority and rationality of the proposed hybrid method.

6.1 Superiority of affinity diagram

Affinity diagram is introduced to select potential CSFs in our hybrid method, results shown in the last section shows these 10 factors' activation degrees are larger then 0.5 when

Table 13 Factors influencing emergency management in positive perspective

Category	Ranking	Importance
F8	The security of relief aids during distribution and transportation	0.7365
F1	Well-planned emergency relief supply system	0.7131
F7	Timely and accurate relief needs assessment	0.7054
F9	Clear procedure of reporting and submitting information	0.6479
F3	Applicable emergency response plan and regulations	0.6458
F10	Application of modern logistics technology	0.6416
F6	Government unity of leadership to plan and coordinate as a whole	0.6395
F2	Reasonable organizational structure and clear awareness of responsibilities	0.6363
F5	Regular organization of simulated disaster exercise	0.6270
F4	Education campaign on disaster prevention and response	0.5930

Table 14 Factors influencing emergency management in negative perspective

Category	Ranking	Importance
F8	The security of relief aids during distribution and transportation	0.7655
F1	Well-planned emergency relief supply system	0.7393
F7	Timely and accurate relief needs assessment	0.7315
F9	Clear procedure of reporting and submitting information	0.6653
F3	Applicable emergency response plan and regulations	0.6612
F10	Application of modern logistics technology	0.6578
F6	Government unity of leadership to plan and coordinate as a whole	0.6545
F2	Reasonable organizational structure and clear awareness of responsibilities	0.6503
F5	Regular organization of simulated disaster exercise	0.6391
F4	Education campaign on disaster prevention and response	0.5981

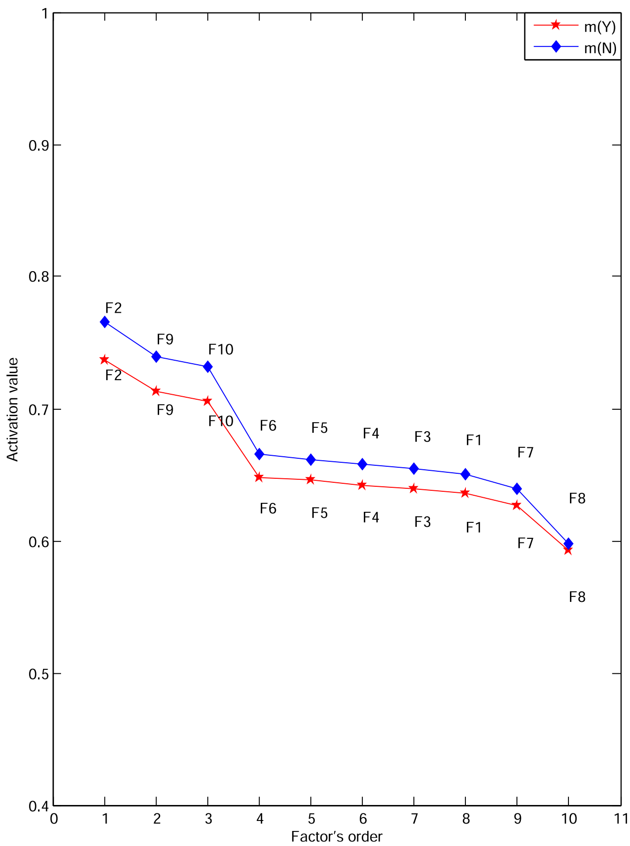

Fig. 7 The order of each CSF

they reach a equilibrium after 6 iterations in FCM. Thus all these discussed factors are CSFs and they exceed the threshold, which means they play a crucial role in high-risk emergency systems.

6.2 Superiority of hybrid DEMATEL-FCM method

Assessment 1: The importance of factors

Figure 8 shows the activation value of each factors both in positive perspective and negative perspective respectively. It can be found that results derived from positive perspective and negative perspective are similar. On the basis of the same linguistic assessment in the form of IFNs initially, the results are consistence. MAE is introduced to quantify the similarity of factors from positive side and negative side, which is calculated by

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|V_Y^i - V_N^i| \quad (8)$$

where the N is the number of influence factors. V_Y^i is ith factors importance in positive while V_N^i is its importance in negative. The MAE of factor importance calculated from positive and negative side is above 0.01765 only trivial difference in these two sides.

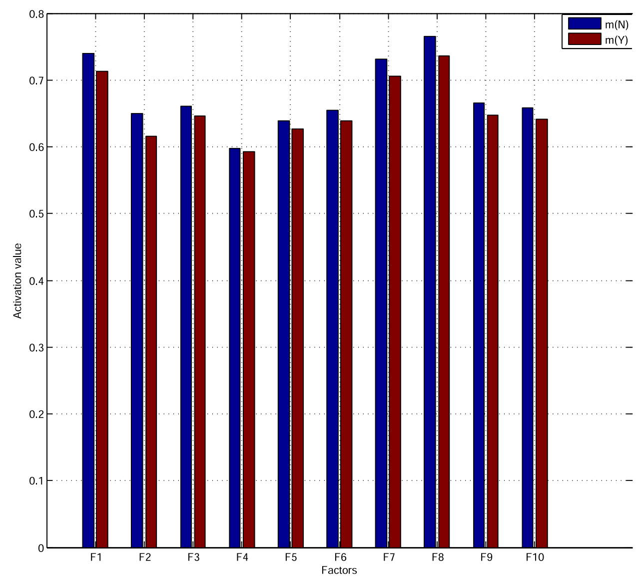

Fig. 8 The activation values of each factor in positive and negative sides

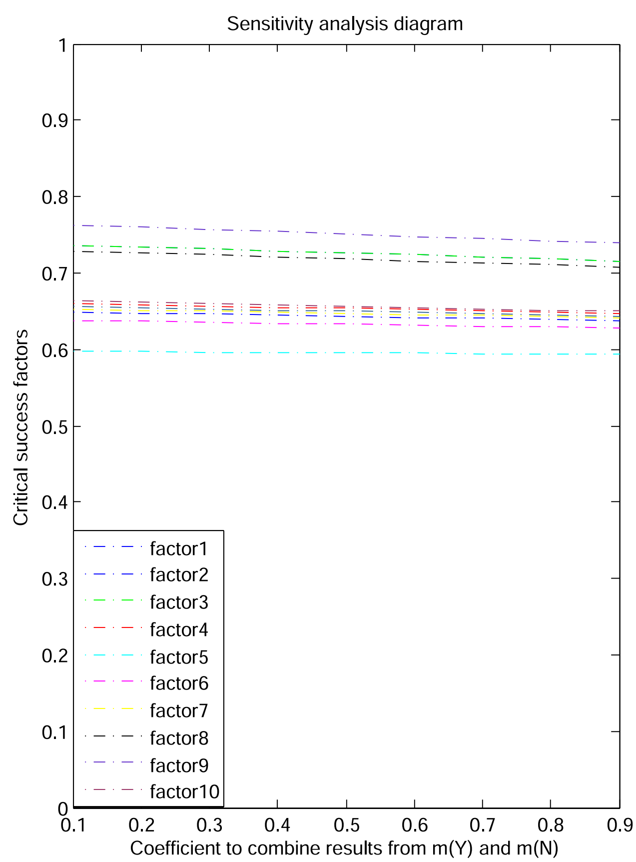

Fig. 9 The sensitivity diagram for CSFs combined results

Assessment 2: Sensitivity

Finally, the two sets of data corresponded to the CSFs are mixed to reach more reliable weights for each CSF. Figure 9 shows the changes of final results by calculating the coefficient from 0.1 to 0.9 that has been used to combine the activation value from positive and negative perspective. Apparently, all the factors are unsensitive to the changes of coefficient which means the results gathered from two sides are not conflict.

6.3 Validation of proposed method

Since the proposed model is an integrated method which combines many multicriteria method to derive a comprehensive result, we implement some existing methods to verify the validness of our model.

6.3.1 DEMATEL method

In this empirical study, DEMATEL method is implemented to identify critical success factors in high-risk emergency systems. According to DEMATEL, a total relationship matrix is obtained after several iterations. Using the values of $R+C$ and $R-C$ where the C is the sum of columns and R is the rows in total relation matrix, a level of influence and a level of relationship are defined. The value of $R+C$ indicates degree of relation between each alternatives which means factors with higher values of $R+C$ have closer relationship with other factors. Thus the factors with higher value of $R+C$ are assumed to be higher priority. And $R-C$ is the severity of influence of each alternative. Factors with higher values of $R-C$ have higher influence to other factors tan those with lower value of $R-C$. The total-relation matrix are shown in Table 15.

Table 15 Rank factors in positive

Order	R	Order	C	Order	$R-C$
F2	2.0141	F8	2.1405	F2	1.1853
F9	1.6797	F1	1.7597	F9	0.714
F6	1.4137	F7	1.6386	F6	0.57954
F10	1.3819	F9	0.9657	F10	0.52733
F8	1.0328	F3	0.8853	F5	0.35285
F5	1.0216	F10	0.85459	F4	− 0.0824
F1	0.74963	F6	0.83418	F3	− 0.18841
F3	0.69689	F2	0.82876	F7	− 0.97043
F7	0.66816	F5	0.66876	F1	− 1.0101
F4	0.16838	F4	0.25078	F8	− 1.1077

Table 16 Rank factors in negative

Order	R	Order	C	Order	$R-C$
F4	3.3609	F4	3.2138	F8	0.93792
F3	2.878	F10	2.7837	F1	0.81821
F7	2.7844	F5	2.7412	F7	0.64719
F1	2.7365	F6	2.7175	F3	0.32878
F5	2.52	F2	2.6414	F4	0.14715
F8	2.4465	F3	2.5492	F5	− 0.22115
F6	2.2365	F9	2.3851	F9	− 0.3792
F10	2.1977	F7	2.1372	F6	− 0.4809
F9	2.0059	F1	1.19183	F10	− 0.58599
F2	1.4294	F8	1.5805	F2	− 1.212

According to Table 15, index of R, C, and $R-C$ can be computed according to Tables 11 and 12, as shown in Tables 15 and 16. As factors having higher $R-C$ values have higher influence to another factors. As shown in Tables 15 and 16, "Reasonable organizational structure and clear awareness of responsibilities" (F2) has the highest value $R-C$ on $m(Y)$ and $m(N)$, which means that F2 dispatches more impact on emergency management. In addition, F2 has the highest value of R on $m(Y)$ and $m(N)$ which indicates F2 has remarkable impact on other factor. In the similar way, the factor "Clear procedure of reporting and submitting information" (F9), "Government unity of leadership to plan and coordinate as a whole" (F6) and "Application of modern logistics technology" (F10) have higher values $R-C$ on $m(Y)$ and $m(N)$, which shows these factors have higher impacts on other factors. The DEMATEL reveals a comprehensive visualized inner relations among factors.

6.3.2 Comparison DEMATEL-FCM with FCM

In this section, we set Fuzzy Cognitive Map (FCM) as the benchmark to compare with our proposed DEMATEL-FCM method. It should be noticed that the difference of these two model is that the weights of DEMATEL-FCM are acquired from DEMATEL while the weights of FCM are from direct evaluations. In this case, the FCM reaches steady state after about 6 iterations as shown in Fig. 10. The activation value of each factors in these two model are showed in Table 17.

As can be seen in Table 17, the results obtained from DEMATEL-FCM and FCM are coinciding both in positive perspective and negative perspective. However, the interactions among different factors are quantified through DEMATEL in DEMATEL-FCM model, which means the results are more accuracy and comprehensive than initial experts evaluations of experts in FCM.

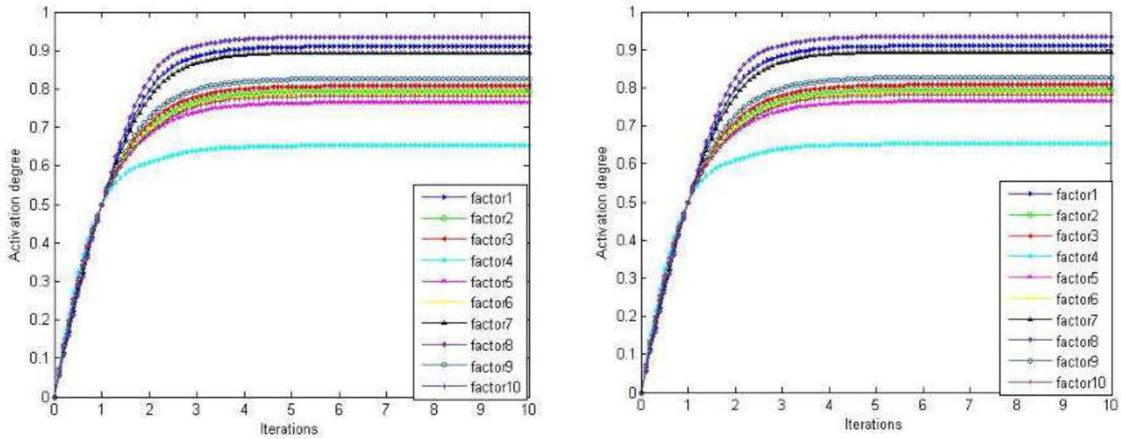

Fig. 10 Results of FCM simulations from positive and negative perspectives

Table 17 Results of DEMATEL-FCM and FCM

Category	Positive perspective				Negative perspective			
	FCM-DEMA-TEL	Rank	DEMATEL	Rank	FCM-DEMA-TEL	Rank	DEMATEL	Rank
F1	0.7131	2	0.104	2	0.7393	2	0.9122	2
F2	0.6363	8	0.7942	8	0.6503	8	0.7971	8
F3	0.6458	5	0.8078	5	0.6621	5	0.8100	5
F4	0.5930	10	0.6530	10	0.5981	10	0.6551	10
F5	0.6270	9	0.7642	9	0.6391	9	0.7674	9
F6	0.6395	7	0.7869	7	0.6545	7	0.7905	7
F7	0.7054	3	0.8947	3	0.7351	3	0.8984	3
F8	0.7365	1	0.9347	1	0.7655	1	0.9434	1
F9	0.6479	4	0.8267	4	0.6653	4	0.8321	4
F10	0.6416	6	0.7822	6	0.6578	6	0.7876	6

7 Conclusion

In this paper, a hybrid method to calculate the CSF is proposed. Identifying the CSFs in the high-risk emergency system is a novel efficient way to management whole system due to the limited of resources. This approach requires the factors which have a higher activation degree when dangerous occurs. Affinity Diagram is employed as efficient tool to select some potential CSFs in high-risk emergency system. Since the interaction among the factors are too complicated to quantify, DEMATEL method is introduced to identify the relations among factors. On the other hand , considering the interplays among factors and the degree being simulated, the FCM has been utilized. FCMs are fuzzy-graph structures for representing causal reasoning. Actually it is a soft computing method obtained as a result of the combination of fuzzy logic and neural network methodologies. It is based on the exploitation of integrated experience of experts. Through applying this method, accurate result has been acquired. In order to decrease the uncertainty, multiple experts in emergency area are invited to evaluate the interactions among factors, Dempster–Shafer evidence theory is implemented as a tool to aggregate opinions of these experts. The framework of the proposed method is displayed in Fig. 11. An empirical case is utilized to verify the effectiveness of our method and the results show that our method is a comprehensive and accurate method. This proposed hybrid MCDM method has a wider application in the high-risk area where disasters frequently occur.

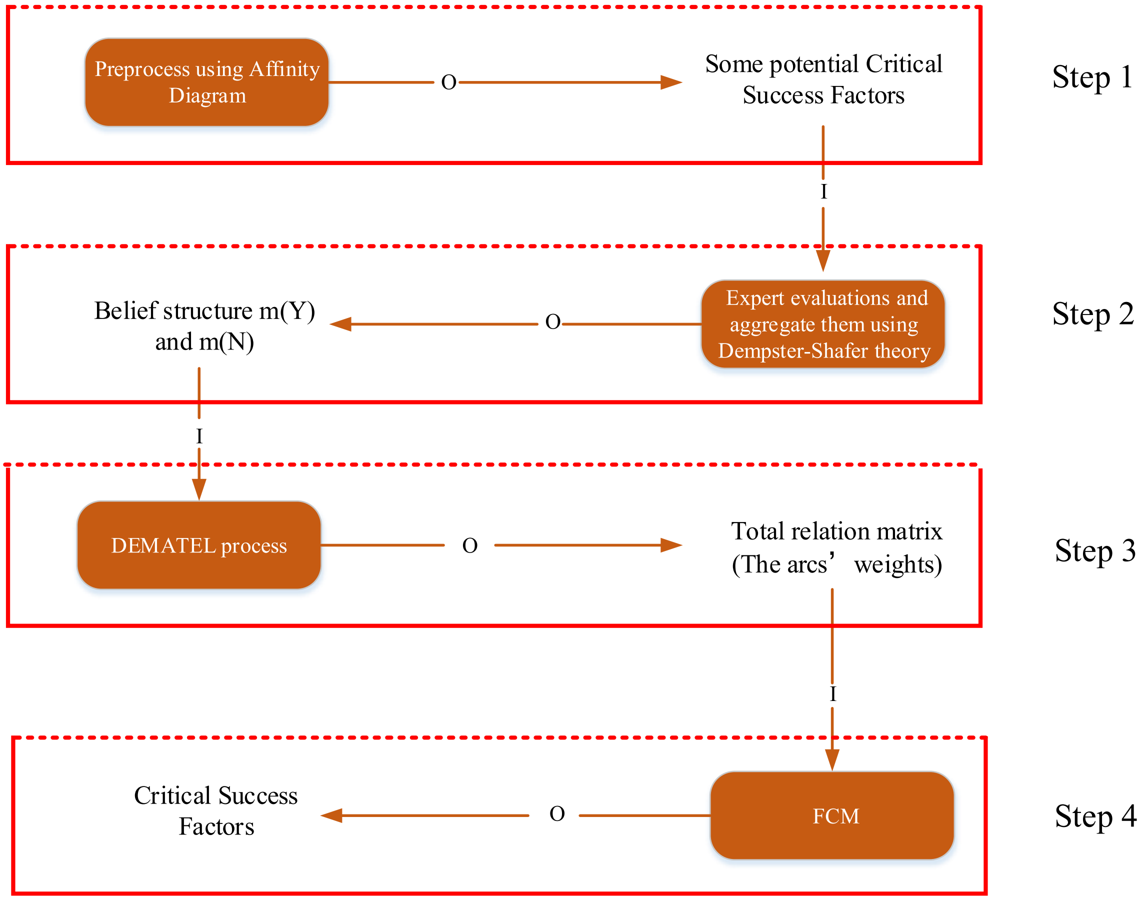

Fig. 11 The framework of the proposed method

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Compliance with ethical standards

Conflict of interest Yuzhen Han declares that he has no conflict of interest. Yong Deng declares that he has no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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